State of Kansas
Exceptional Event Demonstration Package
April 6, 12, 13, and 29, 2011

Department of Health and Environment
Division of Environment
Bureau of Air

September 25, 2012

This document contains blank pages to accommodate double-sided printing.

Acknowledgments

The Kansas Department of Health and Environment would like to thank Sonoma Technology, Inc. (STI) for extensive contributions to Sections 1 and 2, Sections 4 through 8, and Appendices C and D. STI contributors include Daniel Alrick, Kenneth Craig, Clinton MacDonald, Hilary Hafner, and Mary Jo Teplitz.

Table of Contents

Section **Page**

List of Figures

Figure **Page**

Figure **Page**

Figure **Page**

Figure **Page**

Figure **Page**

List of Tables

Table **Page**

1. Overview

Eastern Kansas contains three main metropolitan areas: Kansas City, Wichita, and Topeka. East of Wichita are the Flint Hills, a region of rolling grassland stretching from north of Topeka southward to the Oklahoma border. In April 2011, smoke from numerous fires in the Flint Hills and from other large fires in Texas and Mexico impacted air quality in Kansas metropolitan areas. Fires in the Flint Hills were particularly extensive on April 6, 12, and 13. The smoke that was transported downwind from the fires on these days contributed to ozone formation[1] and exceedance of the National Ambient Air Quality Standard (NAAQS) for 8-hour ozone at several air quality monitors. On April 29, smoke was transported northward into Kansas from several large fires in Texas and Mexico, contributing to ozone formation and exceedance of the NAAQS for 8-hour ozone at air quality monitors in the Wichita area.

The purpose of this report is to provide evidence that the daily peak 8-hour average ozone concentrations in exceedance of the NAAQS on April 6, 12, 13, and 29, 2011, were the result of smoke generated by fires in areas upwind of the monitors where the exceedances occurred. The NAAQS for 8-hour ozone concentration is 0.075 ppm; 8-hour ozone concentrations above 0.075 ppm are above the standard. This document demonstrates that the 8-hour ozone concentrations above 0.075 ppm meet the requirements for having been influenced by an exceptional event as stated in the U.S. Environmental Protection Agency's (EPA) Exceptional Events Rule (72 FR 13560, March 22, 2007).

Table 1-1 shows the specific dates, monitors, and 8-hour ozone concentrations above 0.075 ppm that were reported in Kansas in April 2011. The locations of these monitors, and other nearby air quality and meteorological monitors, are shown in **Figures 1-1 and 1-2**. Please note that all times shown in this report are in 24-hour format and in Central Standard Time (CST).

Table 1-1. Kansas monitors with 8-hour ozone concentrations exceeding 0.075 ppm in April 2011.

Monitor	AQS Site Code	Date in 2011	Observed 8-Hour Ozone Concentration (ppm)
Mine Creek	201070002	April 6	0.076
Peck	201910002	April 6	0.082
Wichita Health Dept.	201730010	April 6	0.079
KNI-Topeka	201770013	April 12	0.084
Konza Prairie	201619991	April 12	0.078
Konza Prairie	201619991	April 13	0.079
Peck	201910002	April 29	0.077
Sedgwick	201730018	April 29	0.082

[1] Smoke from biomass burning contains volatile organic compounds (VOCs) and nitrogen oxides (NO_x), which react to form ozone.

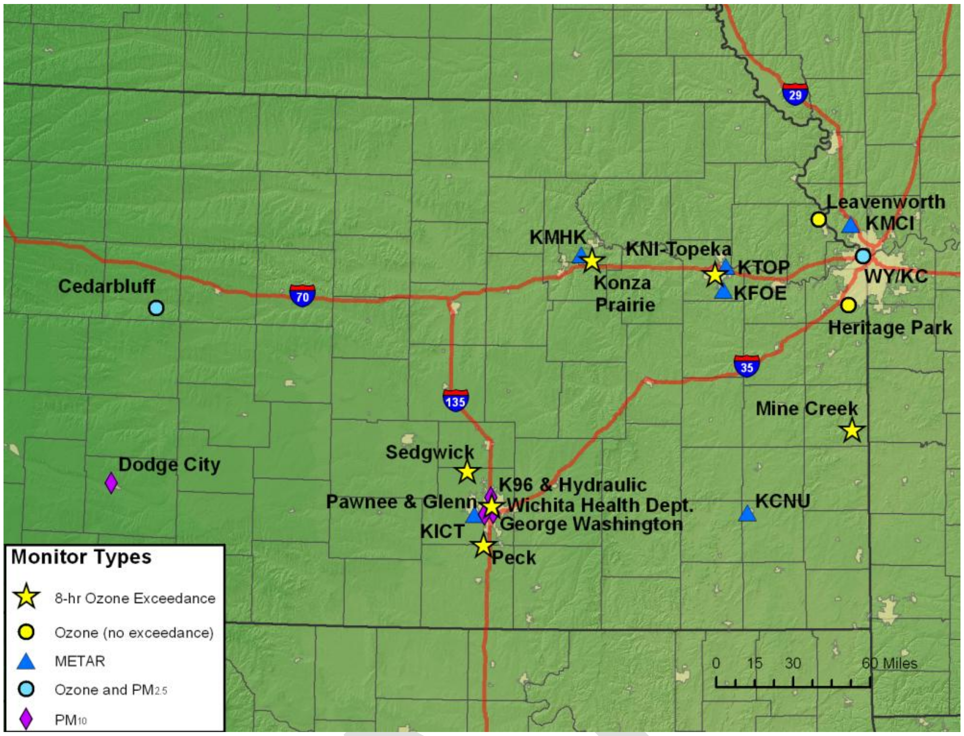


Figure 1-1. Kansas air quality and meteorological (METAR) monitoring sites.

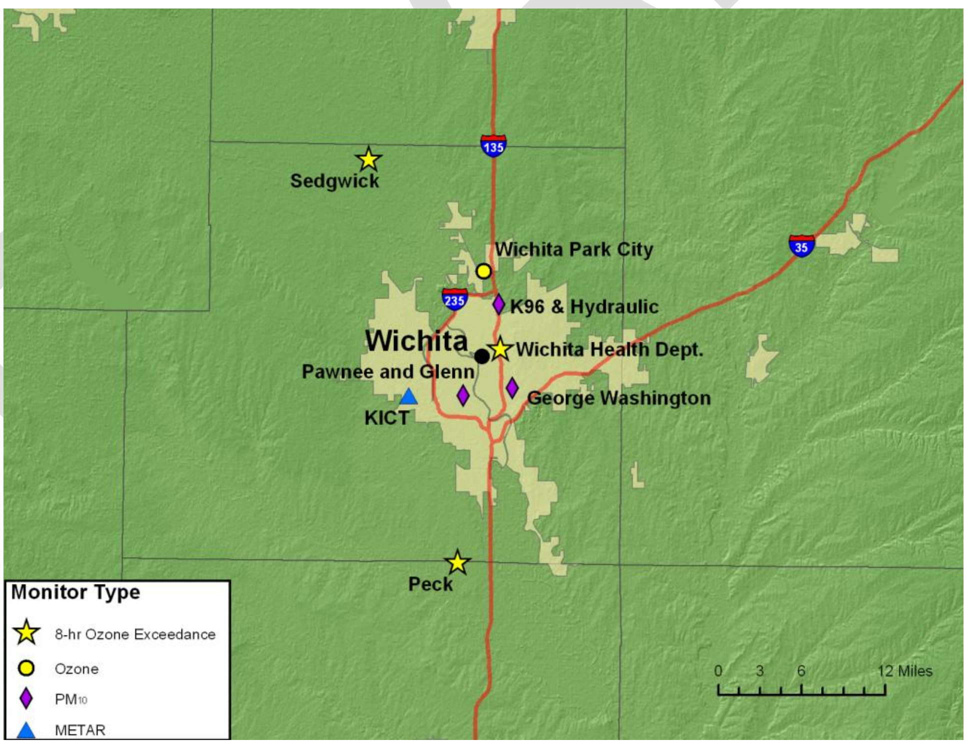


Figure 1-2. Wichita area air quality and nearby meteorological monitoring sites.

1.1 Exceptional Event Definition and Demonstration Criteria

The Exceptional Events Rule is defined in 40 CFR §50.1(j) as an event that

- affects air quality;
- is not reasonably controllable or preventable; and
- is caused by human activity that is unlikely to recur at a particular location or is a natural event.

As specified in 40 CFR 50.14(c)(3)(iv), to justify the exclusion of air quality data from NAAQS determination, the following must be demonstrated:

1. the event was not reasonably preventable;
2. there was a clear, causal relationship between the 8-hour ozone concentrations at the impacted monitors and the specified event;
3. the measured values were in excess of normal historical fluctuations; and
4. no exceedance would have occurred but for the event.

40 CFR Part 50.14(b)(3) grants EPA the authority to exclude data from use in determination of exceedances and NAAQS violations provided that emissions from prescribed fires meets 40 CFR Part 50.1 (j), if the State has ensured that the burner employed basic smoke management practices. In addition, as stated in the Exceptional Events Rule, "Consistent with historical practice governed by guidance contained in the Interim Air Quality Policy on Wildland and Prescribed Fires…, EPA approval of exceedances linked to a prescribed fire used for resource management purpose is contingent on the State to certify that it has adopted and is implementing a Smoke Management Program (SMP[2]) as described in that policy." The SMP should address the following elements:

- **Notification**
  KDHE addressed this issue in the SMP and a brief discussion is included in this document in Section 1.2.1
- **Education**
  KDHE addressed this issue in the SMP and a brief discussion is included in this document in Section 1.2.2
- **Dispersion**
  KDHE addressed this issue in the SMP and a brief discussion is included in this document in Section 1.2.3
- **Mitigation**
  KDHE addressed this issue in the SMP and a brief discussion is included in this document in Section 1.2.4

[2] The Flint Hills Smoke Management Plan can be downloaded at http://www.ksfire.org/~/doc4661.ashx.

1.2 Flint Hills Smoke Management Plan

The Kansas Department of Health and Environment (KDHE), with the assistance of numerous stakeholders, developed the Kansas Flint Hills Smoke Management Plan in 2010 and it was formally adopted by the KDHE in December of 2010. The actual beginning of the process that has led to the development of this plan began in the fall of 2003, when KDHE staff presented information regarding the effects of the Flint Hills burning on ozone levels to agricultural interests at a conference at Kansas State University (KSU). KSU range management researchers, KSU Research and Extension, the Kansas Department of Agriculture, the Kansas Livestock Association, and other agricultural interests were all present at the meeting. With the help of the organizations present, KDHE planned to take an initial voluntary/educational approach to addressing the issue. KDHE continued to engage the agricultural community on this issue in the following years and after a second episode in April 2009, in which the smoke from the burning in the Flint Hills contributed to exceedances of the ozone standard in Kansas City and Wichita, KDHE and the agricultural community agreed that a more formal plan to address this issue needed to be developed.

In early 2010, after several informal meetings and hearings by the Senate Natural Resources Committee on this issue, a formal Flint Hills Smoke Management Advisory Committee was formed to begin the task of developing a Smoke Management Plan (SMP) for the Flint Hills. This committee was co-chaired by Senator Carolyn McGinn, Representative Tom Moxley and the Director of the Division of the Environment at KDHE, John Mitchell, and included a wide range of stakeholders including the Kansas Department of Agriculture, Kansas Fire Marshal, Kansas Division of Emergency Management, Kansas Forest Service, Kansas State University, City of Wichita, Johnson County, Natural Resources Conservation Service, Kansas Livestock Association, Kansas Farm Bureau, Tallgrass Legacy Alliance/ Greenwood County Extension, The Nature Conservancy, American Lung Association (Wichita), Kansas Prescribed Fire Council/KS Grazing Lands Coalition, Sierra Club, Kansas State Firefighters Association, Kansas Emergency Managers Association, Audubon of Kansas and the Kansas Forage and Grasslands Council.

The first large meeting of the group occurred in April 2010 and at that time the advisory committee formed a smaller subcommittee that was tasked to write the Flint Hills SMP. This subcommittee met several times during the late spring and early summer and developed several draft concepts of items to be included in the SMP. These ideas and a draft outline of the SMP were then presented at a second meeting of the SMP Advisory Committee in August. Additional meetings and conference calls of the subcommittee addressed remaining issues and the full draft of the Flint Hills SMP was presented to the Advisory Committee at its third meeting in November. The final meeting occurred in mid-December and included an invitation to the general public to comment on the Flint Hills SMP and its implementation. The plan that has been developed represents a positive first step towards reducing the impacts of Flint Hills burning on air quality in downwind areas. The plan includes contingency measures to be evaluated for potential adoption in the event that further actions are needed. The plan was first implemented in the spring of 2011. This plan was developed to assist in mitigating the effects of the prescribed burns in the Flint Hills to downwind metropolitan areas.

1.2.1 Notification

Beginning in 2009, KDHE began issuing a yearly general “Air Quality Health Advisory” in March before the main burning of the Flint Hills begins. This advisory to the general public informs them of the important reasons for burning in the Flint Hills and of the potential health impacts that could be expected if these smoke plumes enter their areas. KDHE staff also monitors burning conditions throughout the months of March and April and beginning in 2010, if conditions are favorable for significant rangeland burning, a specific health advisory for the following days is issued (see **Appendix A**). In addition, private land managers in many Flint Hills Counties are required by their county or voluntarily notify their local authorities before they burn and the location of that burn. As part of the Flint Hills SMP, nine counties participated in a pilot program in which the land managers called into their local agency and reported when and how many acres they anticipated they were going to burn that day, followed later by an additional call where they reported actual burned acreage.

1.2.2 Education

In order to effectively implement the Kansas Flint Hills Smoke Management Plan, a coherent program of outreach, education, and public notification was conducted. Kansas State University Agricultural Extension Service and many others have taken extensive measures to ensure that the basic smoke management practices described in detail in the plan are followed through education and outreach efforts to farmers and ranchers using prescribed burning as a management practice. The plan was also the driving force for creation of a website (www.ksfire.org), hosted by KSU Extension, which has extensive educational materials and a modeling tool to allow land managers to determine if meteorological conditions are good for dispersing smoke from fires they are planning. Land managers, agencies, trade associations, and non-profit organizations with a stake in prescribed fire in Kansas used the resources they had available to promote adoption and implementation of the Kansas Smoke Management Plan. Information to be included in outreach and education activities include: the impacts of smoke from prescribed fires and the necessity of a plan; the Plan itself; explanation of how the plan is anticipated to work; the responsibilities of entities and individuals in implementing the plan; the process by which the Plan will be evaluated and modified as necessary; the reasons for prescribed fire, with emphasis on the necessity of prescribed fire for maintaining the ecological integrity of native rangelands; and actions taken by municipalities to protect citizens’ health and attain air quality standards.

1.2.3 Dispersion

Chapter Three of the Flint Hills SMP was dedicated to discussing ways and tools that the Flint Hills land managers could use to limit the effects the smoke from their fires had on downwind locations. These fire management practices (FMPs) were a key tool used in the SMP and form the foundation of a good smoke plan. These FMPs ranged from basic questions that the land manager should ask him or herself before burning like “Should I burn this Year?” and “Are there alternatives to burning?” to “When should I burn?” If there were no alternatives to burning, then several burn practices were discussed in the SMP to reduce the impacts on air quality. These included existing air quality on day of proposed burn, transport winds, mixing height, timing of burn, ignition and burn techniques, relative humidity, fuel moisture and air temperature. A check list of recommended parameters for good smoke dispersion was developed and shared with the land managers. Another large component of this section of the SMP was the development of a modeling tool on the ksfire.org website that would allow quick determination by the land manager as to whether their fire and other fires in their particular county would have a detrimental effect on downwind air quality monitors. The tool would allow them to make informed decisions about whether to continue with their planned burn or perhaps if conditions warranted, postponing that burn in order to not affect a downwind monitor.

1.2.4 Mitigation

Finally, evaluation of the effectiveness of the SMP is a key component of ensuring the plan is having the intended goal of reducing the adverse air quality impacts associated with burning in the Flint Hills. It is important to recognize that since the Flint Hills SMP was only adopted in December of 2010 and only three months of implementation were available before the 2011 burn season, KDHE was challenged to implement many of the necessary tools and important education materials concerning the plan. Evaluation of the plan will be ongoing with input from all stakeholders, including land managers, EPA, environmental groups etc. If the technical evaluation demonstrates that Flint Hills burning caused or significantly contributed to a violation of either air quality standard, KDHE will convene a meeting or series of meetings to determine appropriate contingency measures to implement to help maintain the NAAQS. As the plan is evaluated and improved with modifications, contingency measures can be implemented that will help further reduce impacts of burning on air quality.

At the end of the 2011 season, the SMP subcommittee held a meeting to discuss the plan and its implementation during the spring of 2011. The committee discussed the just concluded burn season and improvements and actions needed in 2012. Discussions centered on the challenges to implement the plan in 2011 because the plan was only adopted in December of 2010. This short timeframe from adoption to implementation challenged KDHE and it’s partners to allow the information in the plan to be fully explained and implemented by all ranchers in the Flint Hills. It was agreed by the subcommittee that this process will take some time to reach all those concerned and for the ranchers to make informed decisions on the impact of their burns. The following describes the action items that participants in the Flint Hills Smoke Management Plan identified as priorities for the 2012 burn season. The following education and outreach tasks have been identified:

1. Education and outreach for county commissioners.
    a. Goal: increase the awareness of the issues involved in the SMP and the role that the county commissioners and their staffs can play in the plan implementation.
    b. Present at Kansas Association of Counties Meeting, November 13-15, 2011.
    c. KDHE District Environmental Administrators will meet with county commissioners prior to burn season to build awareness of plan and its implementation.
2. Education and outreach for counties and emergency management staff.
    a. Goal: increase number of dispatchers/fire dept. staff who encourage those calling in for permission to burn to consider the daily smoke designation for their area
    b. Present on urban air quality efforts at annual meeting, September 13-16, 2011.
3. Education and outreach for park managers

   a. Presentation at association meeting, January 2012
      i. When to burn for management goals (wildflower production)?
4. Education and outreach for producers
   a. Goal: increase the number of producers who use the model and consider smoke movement immediately prior to burning
      i. “Are you aware of these resources…”
   b. Promote Clenton Owensby’s research work: leave 20% unburned if possible, don’t go back and burn patches if less than 30% of the total.
      i. Written by Clenton and distributed 31 May 2011.
   c. Include smoke management in prescribed burning workshops.

Other activities were identified as priorities and were implemented before the 2012 season. These included the following:

1. Fire Management Practices pamphlet revisions and reprinting
   a. Change KDHE logo
   b. Add April Burning Restrictions information to the pamphlet

2. Website changes
   a. Add Farm Service Agency (FSA) extended burn window regulation for CRP to website

3. Revise FAQ sheets and improve or provide more clarifications if necessary.

4. E-mail Listserv modification
   a. Include counties adjacent to targeted counties in all e-mails related to springtime burning.

5. Address equipment issues with burning in March
   a. Freezing at night
   b. Work with agricultural engineers to get tip sheet for winterizing sprayers
   c. Work with agricultural engineers for simple modification to pumps allowing fast draining

For use during the 2012 burn season, modifications and improvements were made to the BlueSky smoke modeling tool available on the SMP website, www.ksfire.org. These modifications included the following:

Improve the Resolution of Burn Products

We previously developed a system that automatically runs the BlueSky Framework with the HYSPLIT dispersion model at 21 hypothetical prescribed burn locations. This system produces spatial maps of predicted downwind air quality impacts for a variety of burn sizes and fuel loadings, maps of county-specific cumulative impact potential, and smoke dispersion maps for individual counties. To improve the spatial resolution of the model products, we increased the number of hypothetical prescribed burn locations from 21 to about 40. This will result in estimates of cumulative and individual fire impact potential at a sub-county level. In addition, the maps used to display cumulative and individual fire impact potential will be revised. The number of fuel loading options will remain at three.

Improve the SMP Website Model Section

We made the following changes to the Modeling Section of the Flint Hills Smoke Management website to improve its design and functionality in preparation for operations in 2012:

1. Add several cities to the base maps on the Cumulative Fire Impacts page and the Your Fire Impacts page.
2. Add a pollutant concentration legend to the base map.
3. Slow down the time lapse animations.
4. Change the modeled smoke plume colors to make them more visually apparent against map background.
5. Apply smoothing to smoke plume contours.
6. Add a simple tool to allow stakeholders to select fuel loads based on three images of different fuel loading amounts and associated text descriptions.
7. Allow a longer time period for viewing present day smoke forecasts before transitioning to the next 24 and 48 hour forecasts.

KDHE and the SMP subcommittee will continue to hold these meetings after each burn season.

1.3 Summary of Approach

Several analysis methods were used to develop a weight of evidence to demonstrate that the 8-hour ozone concentrations above 0.075 ppm in April 2011 meet the rules for data exclusion as Exceptional Events. In summary, synoptic and local scale meteorological data, including trajectory analysis, were used to assess whether conditions were favorable for transport of smoke from the fires to the monitors that showed 8-hour ozone concentrations above 0.075 ppm. The presence of smoke at the impacted monitors was evaluated with PM_{10}, $PM_{2.5}$, and visibility data. The 8-hour ozone concentrations on the four smoke event days in April 2011 were compared to concentrations observed in previous Aprils to assess whether the 8-hour ozone concentrations above the NAAQS in April 2011 were historically unusual. Two analyses were used to investigate whether the 8-hour ozone concentrations above 0.075 ppm would have occurred but for the smoke: (1) analysis of ozone concentrations on days with similar meteorological conditions but without smoke impacts and (2) analysis of results from photochemical model simulations with and without fires. The estimated ozone contribution due to fires from each method was subtracted from the observed 8-hour ozone concentrations. If the result of that subtraction was less than 0.076 ppm, the analysis demonstrates that the observed 8-hour ozone concentration in exceedance of the NAAQS would not have occurred.

1.4 Summary of Findings

This report demonstrates that

- the smoke events in question were not reasonably preventable (Section 2);
- there was a clear causal relationship between the fires and the 8-hour ozone exceedances (Section 3);

- ozone concentrations during the event were in excess of historical norms (Section 4); and
- the ozone exceedances would not have occurred but for the smoke from the fires (Section 5).

Therefore, the findings strongly suggest that all of the 8-hour ozone concentrations above 0.075 ppm in Kansas in April 2011 meet the rules for exclusion as Exceptional Events. Brief synopses of the meteorological and air quality conditions on each smoke event day are presented below.

April 6, 2011 Event

On April 6, 2011, about 248,358 acres were burning in the Flint Hills of Kansas. A cold front moved across Kansas on April 6, with northerly surface winds behind the cold front, and southerly winds ahead of the front (**Figure 1-3**). As the front moved through the Wichita area around midday, northerly winds transported smoke from fires in the Flint Hills to the Wichita Health Dept. and Peck monitors. Ahead of the front, southwesterly winds transported smoke from fires in the southern Flint Hills to the Mine Creek monitor. Photochemical modeling and matching day analyses provide evidence that, without the impact from fires, no 8-hour ozone concentrations above 0.075 ppm would have occurred at the Mine Creek, Peck, or Wichita Health Dept. monitors on April 6 (see **Table 1-2**). In addition, because no other unusual emissions were identified on this day and because the estimated concentrations without the fires were well below the NAAQS, it is very unlikely that other sources of ozone would have caused this exceedance.

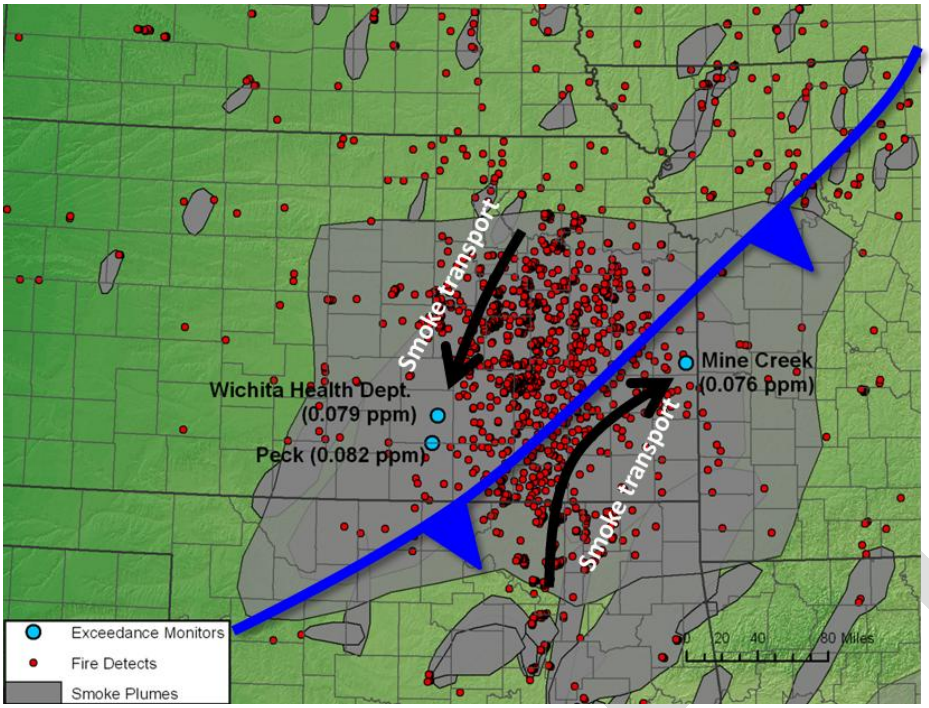


Figure 1-3. Summary of conditions on April 6, 2011. Black arrows denote transport of smoke by winds; blue line denotes approximate location of cold front at noon on April 6. Peak 8-hour ozone concentrations are in parentheses at the impacted monitors. Southerly winds ahead of a cold front transported smoke to the Mine Creek monitor. Northerly winds behind the front transported smoke to Wichita-area monitors. Photochemical modeling showed that smoke enhanced the formation of ozone at the impacted monitors.

Table 1-2. 8-hour ozone concentrations on April 6, 2011, and estimated ozone contributions due to smoke.

Monitor	AQS Site Code	Observed 8-Hour Ozone Concentration (ppm)	Estimated Ozone Contribution from Smoke (ppm)	Estimated 8-hour Ozone Concentration Without Smoke (ppm)	Is 8-hour Ozone Without Smoke Below 0.075 ppm?
Mine Creek	201070002	0.076	0.010 to 0.014	0.062 to 0.066	Yes
Peck	201910002	0.082	0.020 to 0.029	0.053 to 0.062	Yes
Wichita Health Dept.	201730010	0.079	0.020 to 0.028	0.051 to 0.059	Yes

April 12, 2011 Event

On April 12, 2011, about 298,243 acres were burning in the Flint Hills. Light to moderate southerly winds in eastern Kansas on April 12 transported smoke from fires in the Flint Hills region to the KNI-Topeka and Konza Prairie monitors (**Figure 1-4**). This wind pattern also transported smoke away from the Wichita area monitors in southern Kansas and the Mine Creek monitor in eastern Kansas. Photochemical modeling and matching day analyses provide evidence that, without the impact from fires, no 8-hour ozone concentrations above 0.075 ppm would have occurred at the KNI-Topeka and Konza Prairie monitors on April 12 (see **Table 1-3**). In addition, because no other unusual emissions were identified on this day and because the estimated concentrations without the fires were well below the NAAQS, it is very unlikely that other sources of ozone would have caused this exceedance.

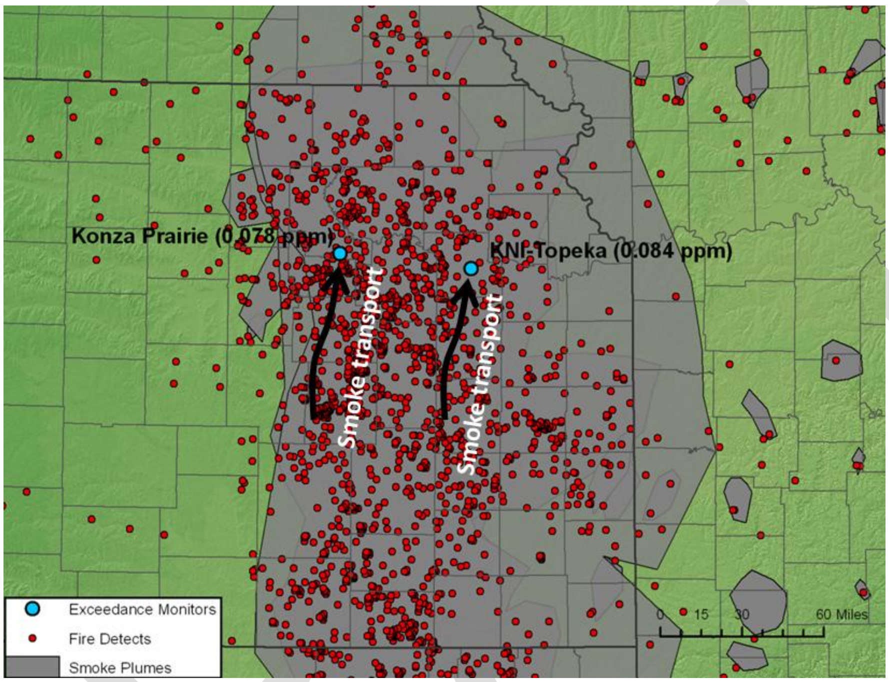


Figure 1-4. Summary of conditions on April 12, 2011. Light to moderate southerly winds transported smoke to the KNI-Topeka and Konza Prairie monitors. Photochemical modeling indicates that the smoke enhanced ozone formation at the impacted monitors.

Table 1-3. 8-hour ozone concentrations on April 12, 2011, and estimated ozone contributions due to smoke.

Monitor	AQS Site Code	Observed 8-Hour Ozone Concentration (ppm)	Estimated Ozone Contribution from Smoke (ppm)	Estimated 8-Hour Ozone Concentrations Without Smoke (ppm)	Is 8-hour Ozone Without Smoke Below 0.075 ppm?
KNI-Topeka	201770013	0.084	0.025 to 0.028	0.056 to 0.059	Yes
Konza Prairie	201619991	0.078	0.007 to 0.019	0.059 to 0.071	Yes

April 13, 2011 Event

On April 13, 2011, about 291,296 acres were burning in the Flint Hills. Light to moderate southeasterly surface winds in eastern Kansas on April 13 transported smoke from fires in the Flint Hills region to the Konza Prairie monitor (**Figure 1-5**). Unlike April 12, when smoke was largely confined to the Flint Hills region, smoke on April 13 was observed over most of Kansas and in portions of neighboring states. Some of this smoke was likely from fires that burned on April 12. Photochemical modeling and matching day analyses provide evidence that, without the impact from fires, no 8-hour ozone concentration over 0.075 ppm would have occurred at the Konza Prairie monitor on April 13 (see **Table 1-4**). In addition, because no other unusual emissions were identified on this day and because the estimated concentrations without the fires were well below the NAAQS, it is very unlikely that other sources of ozone would have caused this exceedance.

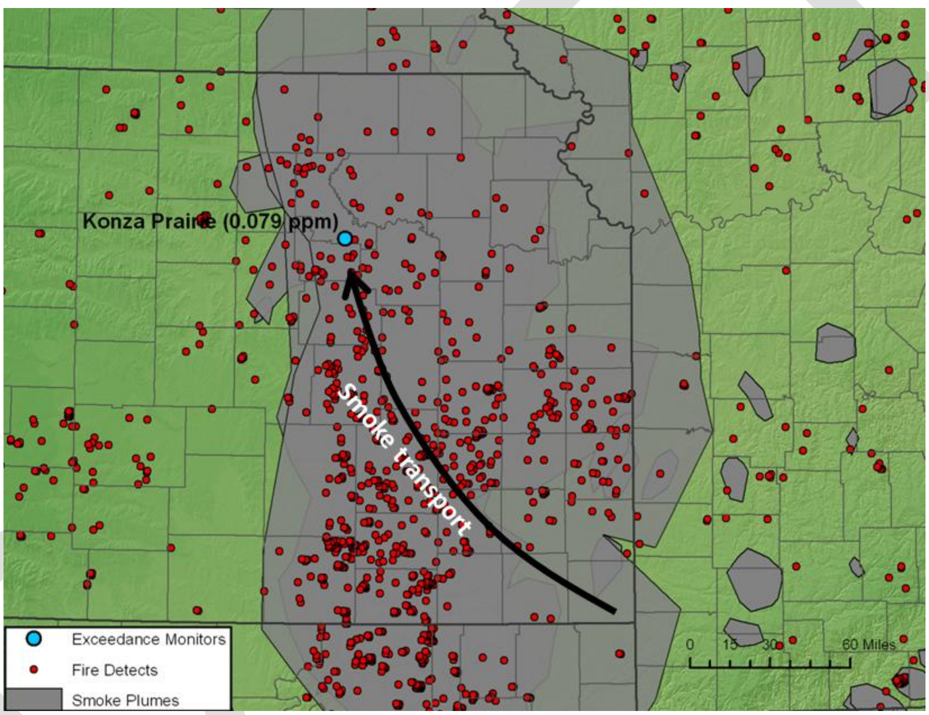


Figure 1-5. Summary of conditions on April 13, 2011. Southeasterly winds transported smoke to the Konza Prairie monitor, enhancing the formation of ozone.

Table 1-4. 8-hour ozone concentration on April 13, 2011 and estimated ozone contribution due to smoke.

Monitor	AQS Site Code	Observed 8-Hour Ozone Concentration (ppm)	Estimated Ozone Contribution from Smoke (ppm)	Estimated 8-Hour Ozone Concentration Without Smoke (ppm)	Is 8-hour Ozone Without Smoke Below 0.075 ppm?

Konza Prairie	201619991	0.079	0.018 to 0.030	0.049 to 0.061	Yes

April 29, 2011 Event

Numerous large fire complexes in Texas and northeastern Mexico, some burning since April 25, produced widespread smoke and haze across the southern Plains on April 29. Strong southerly surface winds transported this smoke into southern Kansas (**Figure 1-6**). The Wichita area monitors were closer to the smoke sources than the other Kansas monitors, and they were therefore impacted by the smoke for a longer period of time on April 29 than the monitors further north. Matching day analysis provided evidence that, without the impact from fires, no 8-hour ozone concentrations over 0.075 ppm would have occurred at the Peck and Sedgwick monitors on April 29 (**Table 1-5**). In addition, because no other unusual emissions were identified on this day and because the estimated concentrations without the fires were well below the NAAQS, it is very unlikely that other sources of ozone would have caused this exceedance. Also, due to the strong winds and associated dispersion, it is very improbable that emissions from upwind cities such as Oklahoma City would have caused this exceedance. This conclusion is supported by the fact that model predictions of ozone concentrations that include anthropogenic emissions from upwind cities were well below the NAAQS.

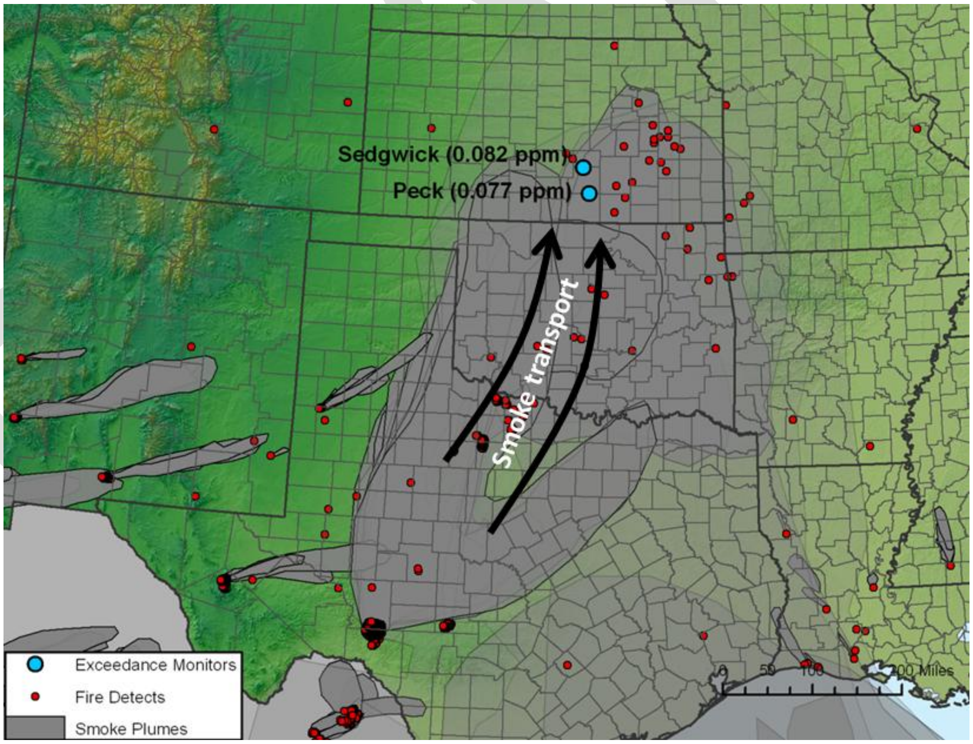


Figure 1-6. Summary of conditions on April 29, 2011. Strong southerly winds transported smoke into the Wichita area, where the smoke enhanced ozone formation.

Table 1-5. 8-hour ozone concentrations on April 29, 2011 and estimated ozone contributions due to smoke.

Monitor	AQS Site Code	Observed 8-Hour Ozone Concentration (ppm)	Estimated Ozone Contribution from Smoke (ppm)	Estimated 8-Hour Ozone Concentrations Without Smoke (ppm)	Is 8-Hour Ozone Without Smoke Below 0.075 ppm?
Peck	201910002	0.077	0.017	0.060	Yes
Sedgwick	201730018	0.082	0.026	0.056	Yes

2. Data Acquisition

Ozone concentrations in excess of the NAAQS normally occur with sunny skies, warm air temperatures, stable atmospheric conditions, and light winds. Ozone concentrations may also increase when there are unusual emissions of ozone precursors such as volatile organic compounds (VOCs) and nitrogen oxides (NO_x). Wildland fires are known sources of these ozone precursors. To analyze the specific conditions on the days when 8-hour ozone concentrations above 0.075 ppm occurred in Kansas in April 2011, fire and smoke, air quality, and meteorological data were first collected from a wide variety of sources (**Table 2-1**). These sources were selected because of their high standards for data quality. Additional meteorological parameters, such as vector average winds and daily maximum temperatures, were calculated as necessary. **Table 2-2** describes why these data are needed to understand and explain the processes that influence ozone conditions.

Table 2-1. Data types and sources used in the Exceptional Events analysis.

Type of Data	Source(s)	Location(s)	Date Range
Air Quality Data: 1-hour and 8-hour ozone 1-hour PM_{10} 1-hour $PM_{2.5}$	KDHE CASTNET[a]	Kansas air quality monitors	March through May, 2006-2011
Surface meteorological data (METAR[b])	National Weather Service (NWS)	All available Kansas sites	March through May, 2006-2011
Upper-air meteorological data (radiosonde)	NWS	Topeka, KS (KTOP) Norman, OK (KOUN)	March through May, 2006-2011
Surface and upper-level weather maps	NWS	National and regional	April 2011
Visible and infrared satellite imagery	NWS	National	March through May, 2006-2011
Daily MODIS[c] Visible satellite imagery	SSEC[d]	National	April 2011
Daily smoke and fire data	NOAA-HMS[e]	National	April 2011
Daily burn acreage estimates	KDHE SmartFire[f]	Flint Hills region	April 2011

[a] Clean Air Status and Trends Network
[b] Meteorological Terminal Aviation Routine Weather Report
[c] Moderate Resolution Imaging Spectroradiometer
[d] Space Science and Engineering Center, University of Wisconsin-Madison
[e] National Oceanic and Atmospheric Administration's Hazard Mapping System
[f] Satellite Mapping Automated Reanalysis Tool for Fire Incident Reconciliation

Table 2-2. Description of processes that influence ozone levels.

Type of Data	Relation to Ozone Levels

Temperature	Surface temperature data were assessed to determine whether temperatures were conducive to high ozone levels. Warmer temperatures enhance ozone formation.
Surface wind speeds	Surface wind data were used to assess pollutant dispersion. Light winds limit pollutant dispersion, and limited pollutant dispersion normally results in higher ozone levels.
Trajectories (HYSPLIT[a])	Trajectory analysis was used to assess transport of pollutants. Air parcels originating in or passing through regions of higher pollution levels (e.g., smoke) indicate potential transport of pollutants to downwind locations.
Upper-air soundings	Soundings were used to assess atmospheric stability (and inversions) and the likelihood that smoke emitted from fires would remain in the lower levels of the atmosphere as opposed to being mixed into aloft layers. Confirming that the smoke would most likely remain in the lower layers of the atmosphere also provides guidance on which trajectory levels are appropriate to assess smoke transport.
Upper-level weather maps	500 mb weather maps were used to determine the locations of upper-level ridges and upper-level troughs. Upper-level ridges are associated with increased atmospheric stability, which reduces vertical mixing and traps pollutants near the surface.
Surface weather maps	Surface weather maps were used to determine the positions of high- and low-pressure systems and frontal boundaries in relation to the impacted monitors. These meteorological features are the primary drivers of surface wind speed and direction, and thus of pollutant dispersion and transport.
Satellite imagery	Satellite imagery was used to assess cloud cover at the impacted monitors. Ozone formation is enhanced in the presence of sunlight; thus, higher ozone levels are normally associated with limited cloud cover.
PM_{10}, $PM_{2.5}$, and visibility	Particle concentrations from air quality monitors and visibility observations from airports were collected to assess the presence of smoke at air quality monitors. Smoke is known to cause elevated PM_{10} and $PM_{2.5}$ concentrations and reductions in visibility.

[a] Hybrid Single Particle Lagrangian Integrated Trajectory Model

3. Not Reasonably Preventable/Unlikely to Recur

3.1 Flint Hills Ecosystem

Grasslands once covered much of middle North America, making up the continent's largest vegetative area. While significantly diminished following Euro-American settlement, North America's native prairies (short, mid and tall) still represent extensive areas of native plant and animal communities. The eastern third of this vast grassland region is represented by tallgrass prairie, a mosaic of distinct herbaceous-dominated communities. Tallgrass prairie is characterized by higher rainfall than mid- and shortgrass prairies to the west and is represented by a few dominant warm-season grasses and numerous herbaceous perennial forbs.

Climate, grazing, and fire, each operating at multiple scales, frequencies, and intensities, were the primary ecological processes that shaped the tallgrass prairie ecosystem. Seasonal precipitation and temperature patterns influenced the growth of vegetation, which in turn affected the availability of fuels for burning and forage for grazing. Frequent fire, interacting with grazing and climate, perpetuated a diverse vegetation mosaic across the prairie landscape. Bison and elk, the principal historic herbivores, grazed preferentially on vegetation in burned areas because of the greater productivity and nutritive quality of forage following fire. Their transitory grazing patterns allowed the vegetation to recover from intermittent and sometimes intensive grazing events. These grazing patterns further impacted the availability of fuel for fire and, in turn, helped maintain the vegetation mosaic. People living on the landscape influenced these patterns and played a large role in shaping the historic landscape prior to Euro-American settlement.

Deep-rooted prairie plants created some of the most fertile soils in the world, making the tallgrass region prime for agricultural development. Much of the historic tallgrass prairie was converted to cropland in a single decade, as railroads and Land Acts provided economic incentives. Tallgrass prairie once stretched across 170 million acres, from Canada to Texas and Kansas to Kentucky. Today, only about 4% remains. Few places in the world have experienced the extent of anthropogenic alteration documented in the tallgrass, making this once expansive, complex ecosystem one of the most altered in North America in terms of acres lost.

Still relatively unspoiled are the Flint Hills in eastern Kansas (**Figure 3-1**) and northeast Oklahoma[3], an extensive, landscape expression of tallgrass prairie. Unlike the now-vanished tallgrass prairies that once blanketed much of the American heartland, this prairie landscape of gently-sloping limestone and chert hills remains today as the continent's last significant, unfragmented expanse of tallgrass prairie. Roughly two-thirds of all tallgrass prairie in North America is contained in the Flint Hills.

[3] The Osage Hills (in Osage County, Oklahoma) represent a southern extension of the Greater Flint Hills landscape.

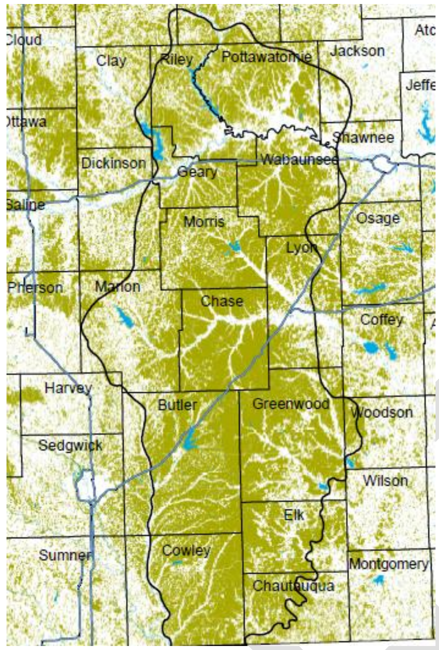


Figure 3-1. Kansas Flint Hills Ecosystem outlined in black. Source: 2004 Statewide United States Department of Agriculture (USDA) National Agriculture Imagery Program (NAIP).

The Flint Hills provide a unique ecosystem representation of tallgrass prairie. Historically, bison served as a keystone species in maintaining biodiversity, but today cattle serve as its surrogate. This large and intact area of tallgrass prairie is perhaps most important to grassland nesting birds, including the greater prairie-chicken (**Figure 3.2**), upland sandpiper, grasshopper sparrow, Henslow's sparrow and other species of conservation concern. The Flint Hills are also thought to provide an important north-south grassland corridor for migrating birds, such as the American golden plover, buff breasted sandpiper and Sprague's pipit. Because of their scale, the Flint Hills harbor one of the continent's largest populations of greater prairie-chickens.

Once believed relatively stable, populations of prairie-chickens in the Flint Hills have declined significantly since the 1980s. Part of the decline is linked to habitat fragmentation from tree encroachment and other habitat intrusions, but is also associated with a lack of residual vegetation for nesting. Fire and grazing are not in themselves detrimental to grassland bird reproduction, and in fact are essential ecological processes; but a decline in reproductive success may occur when the two are combined with high frequency. Henslow's sparrow (**Figure 3-2**), which requires areas of ungrazed or lightly grazed prairie with at least one year's accumulation of residual vegetation, has also experienced population declines. On the other hand, annually burned pastures provide nesting habitat for species that utilize or even prefer short stature vegetation, such as upland sandpiper (**Figure 3.2**), horned lark, and grasshopper sparrow. Burned pastures also provide year-long foraging habitat for grassland birds, winter cover, and the landscape context needed for area sensitive species like prairie chickens. Spring migrants like American golden plovers and buff-breasted sandpipers also seek out burned pastures as foraging areas in the spring.

Figure 3-2. Left: Male Greater Prairie Chickens, Lyon County. Middle: Henslow's sparrow. Right: Upland Sandpiper.

The U.S. Fish & Wildlife Service and The Nature Conservancy have both identified the Flint Hills as a priority conservation action site. Likewise, the Kansas Natural Heritage Inventory rates the Flint Hills as the state's No. 1 landscape conservation priority, and the World Wildlife Fund recognizes the landscape as "one of only six grasslands in the contiguous U.S. that is globally outstanding for biological distinctiveness." In 2001, The Nature Conservancy launched its Flint Hills Initiative, a community-based conservation initiative, to employ multiple strategies to help preserve the biological integrity of the region. The Nature Conservancy also has an impressive portfolio of conservation landholdings in the Flint Hills totaling more than 60,000 acres. These include Konza Prairie, which is operated as a field research station by the Division of Biology at Kansas State University, and the Tallgrass Prairie National Preserve, a unit of the National Park Service. The Nature Conservancy, Kansas Land Trust, Ranchland Trust of Kansas and USDA's Natural Resources Conservation Service (NRCS) also hold more than 60,000 acres of conservation easements in the Flint Hills. Since 2004, these entities have invested more than $12 million in land conservation in the Kansas Flint Hills.

3.2 Unlikely to Recur

Since Euro-American settlement, fire has largely been suppressed in North American grasslands, contributing to range degradation due to woody encroachment. One exception is the extensive use of fire as a management tool by ranchers in the Flint Hills of Kansas and Osage Hills of Oklahoma. Residents here typically view fire as a necessary rangeland practice, whereas outside the region, the general attitude toward fire is often less favorable. Cattlemen recognized early on that burning Flint Hills pastures benefited the condition of their pastures and cattle weight gains. In the years following settlement, a significant portion of the Flint Hills (**Figure 3-3**) were burned on a frequent basis despite academic warnings against the practice, particularly in large pastures grazed by transient cattle. In the 1970s, range scientists began to promote the agricultural and ecological benefits of burning tallgrass prairie. Today, range burning is widely prescribed by range specialists and ecologists alike as a management tool necessary to maintain the ecological integrity of tallgrass prairie. However, the cyclic scheduling of burns varies according to the objective of management practices.

Figure 3-3. Map of Flint Hills counties.

Fire is well documented as a key ecological driver in grassland communities and is (**Figure 3-4**) particularly important in grasslands that receive high precipitation to counter woody encroachment. Lightning-caused fires presumably drove the region's early beginnings as a fire/herbivore-driven plant community. Fire frequency is believed to have increased dramatically as humans gained more of a presence. In fact, Native American burning may have been the dominant ecological force for the past 10,000 years. This increased use of fire is believed to have resulted in an eastward expansion of the tallgrass region.

Tallgrass prairie requires fire on a relatively frequent basis to prevent the encroachment of woody species and maintain the integrity of plant communities. Estimates of pre-1840 fire occurrence rates in tallgrass prairie vary from an annual regime (Edwin et al., 1966), 2 to 5 times per decade (Hulbert, 1973) and every 5 to 10 years (Wright and Bailey, 1982). Cutter and Guyette (1994) estimated a 2.8-year fire interval for a Missouri Savanna, while Bragg and Hulbert (1976) found evidence of a 3 to 5 year pre-settlement burn interval for Nebraska and Kansas tallgrass prairies. Given the historic extent of tallgrass prairie and assuming a 3-5 year historic fire-return interval, 30 to 60 million acres of tallgrass prairie would have burned on average each year.

Fire frequency varies widely depending on the type of livestock operation (e.g., cow-calf, season-long yearlings, and short season stockers), but burning constraints, fire culture, and historic land use also play into the frequency of fire.

Figure 3-4. Prescribed fire in Wabaunsee County.

One of the strongest motivators for land managers to burn is to improve daily weight gains in stocker cattle**,** which are commonly 10 to 15% higher in spring-burned pastures (Vermeir and Bidwell, 1998). While there is less animal performance benefit from burning pastures stocked by cow-calf herds, many land managers burn such pastures on a three-year fire-return interval to control woody plants and other undesirable species. However, tree-infested pastures may require a higher fire-return interval (Vinton, 1993). Land managed for conservation (e.g., Nature Conservancy preserves) is also regularly burned to control woody vegetation and to enhance wildlife habitat. The frequency of burning varies with management practices but generally ranges from every two to three years.

Historically, humid tallgrass prairies are thought to have burned primarily during the dormant season, particularly in autumn by Native Americans, but lightning-caused fires were more common in mid- to late summer. Contemporary pasture burning in the Flint Hills generally occurs in late March through early May, but early Flint Hills ranchers often burned even earlier to stimulate “green-up.” Towne and Owensby (1984) reported that burning of ungrazed prairie in late-spring increased grass production and favored desirable warm season grasses, whereas winter and early- and mid-spring burns favored forbs and sedges.

There is a perception that most of the Flint Hills are intensively grazed and burned each year, but satellite imagery and Kansas Agriculture Statistics suggest these practices do not extend across the entire landscape. An analysis of satellite imagery from 2000 through 2012 indicates that about 1.67 million acres burned on average (range of 1.3 to 2 million acres) within 13 Flint Hills core counties. This translates to 35% of total prairie acres burned, based on a 4.8 million acreage estimate within the core counties. **Figure 3-5** shows the annual percent of total grassland burned across the core Flint Hills counties and **Figures 3-6 and 3-7** show examples of percent of grassland burned by individual counties. It should be noted that the grasslands that are burnt annually extend into three counties of Oklahoma and several peripheral counties surrounding these core counties. Significant burning can and does occur in these counties, especially the three counties of Oklahoma (Osage, Nowata, and Washington).

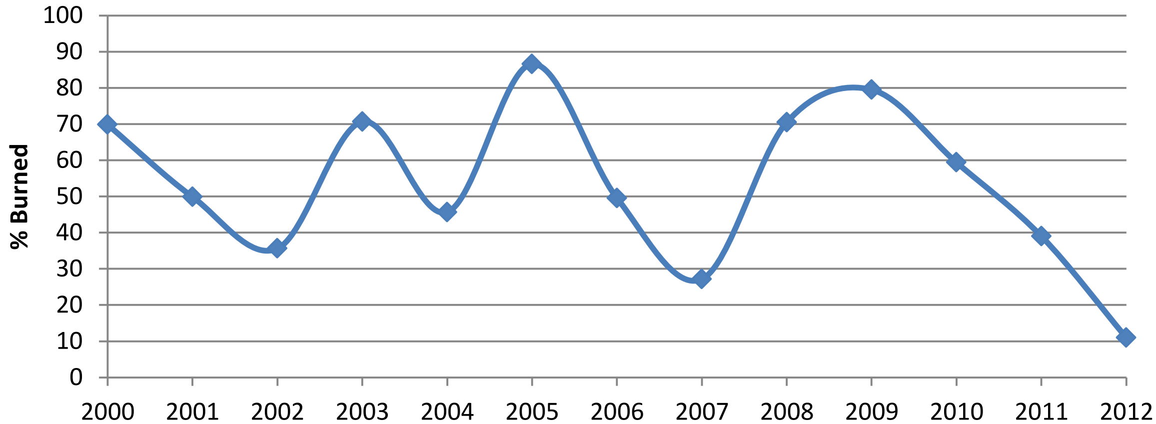


Figure 3-3. Percentage of Flint Hills grassland burned annually, 2000-2012.

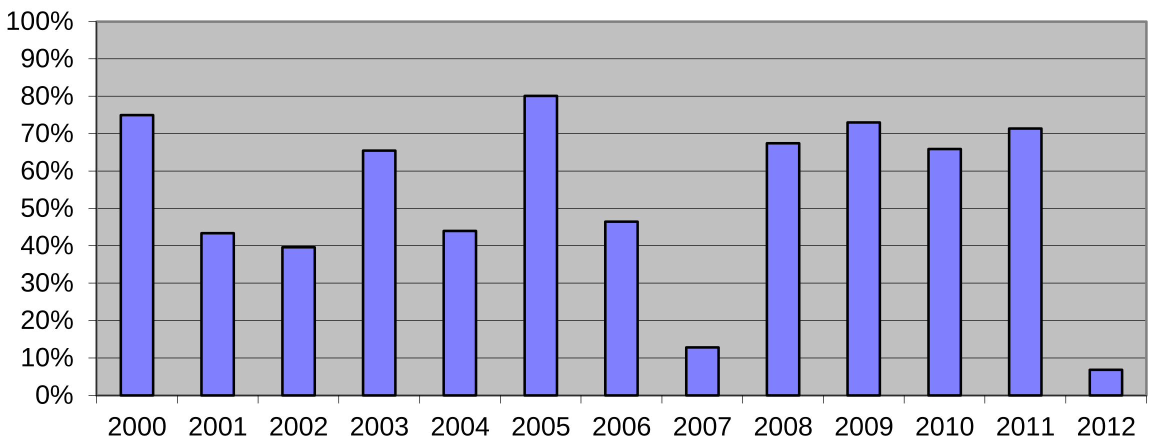


Figure 3-4. Percentage of grassland burned in Chase County annually, 2000-2012.

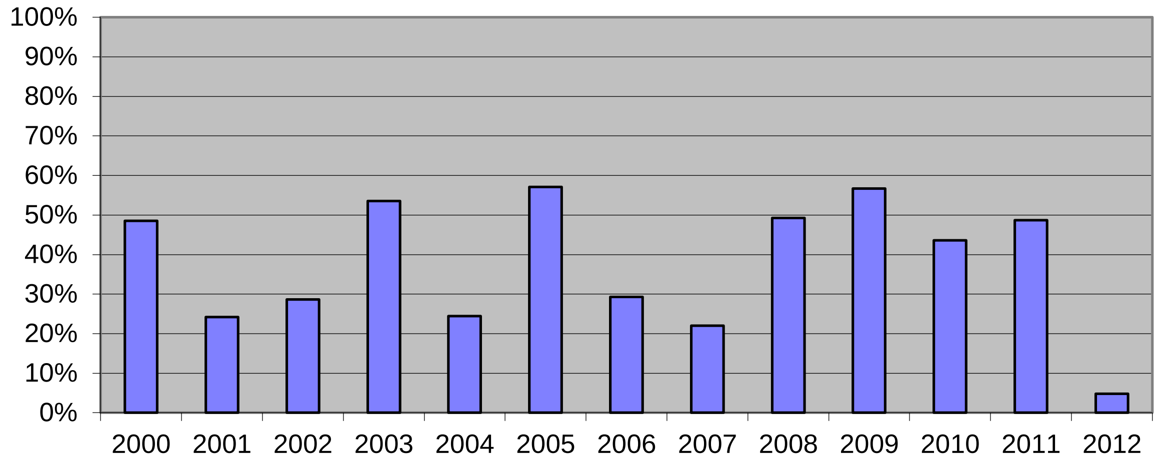


Figure 3-5. Percentage of grassland burned in Greenwood County annually, 2000-2012.

In addition, satellite imagery also revealed that certain areas of the Flint Hills, particularly the more intact areas of the landscape, were burned on a more frequent basis. However, even those areas identified as "dark red" in **Figure 3-8**, which were burned every year over the 11-year period of 2000-2010, only made up a very small percentage of the total number of burnable acres in the Flint Hills. In fact, one can see that the vast majority of acres were either not burned (white) or only burned once (dark blue) in this 11-year time frame. As shown in **Table 3-1**, of all grassland burned at least once in the Flint Hills region between 2000 and 2010, only 1% was burned in all 11 years of the study while 15% was burned in only one year. [4]

[4] Mohler, R. and D. Goodin. 2012. Mapping Flint Hills burning in Kansas and Oklahoma, USA, 2000-2010. Great Plains Research 22(1):15-26.

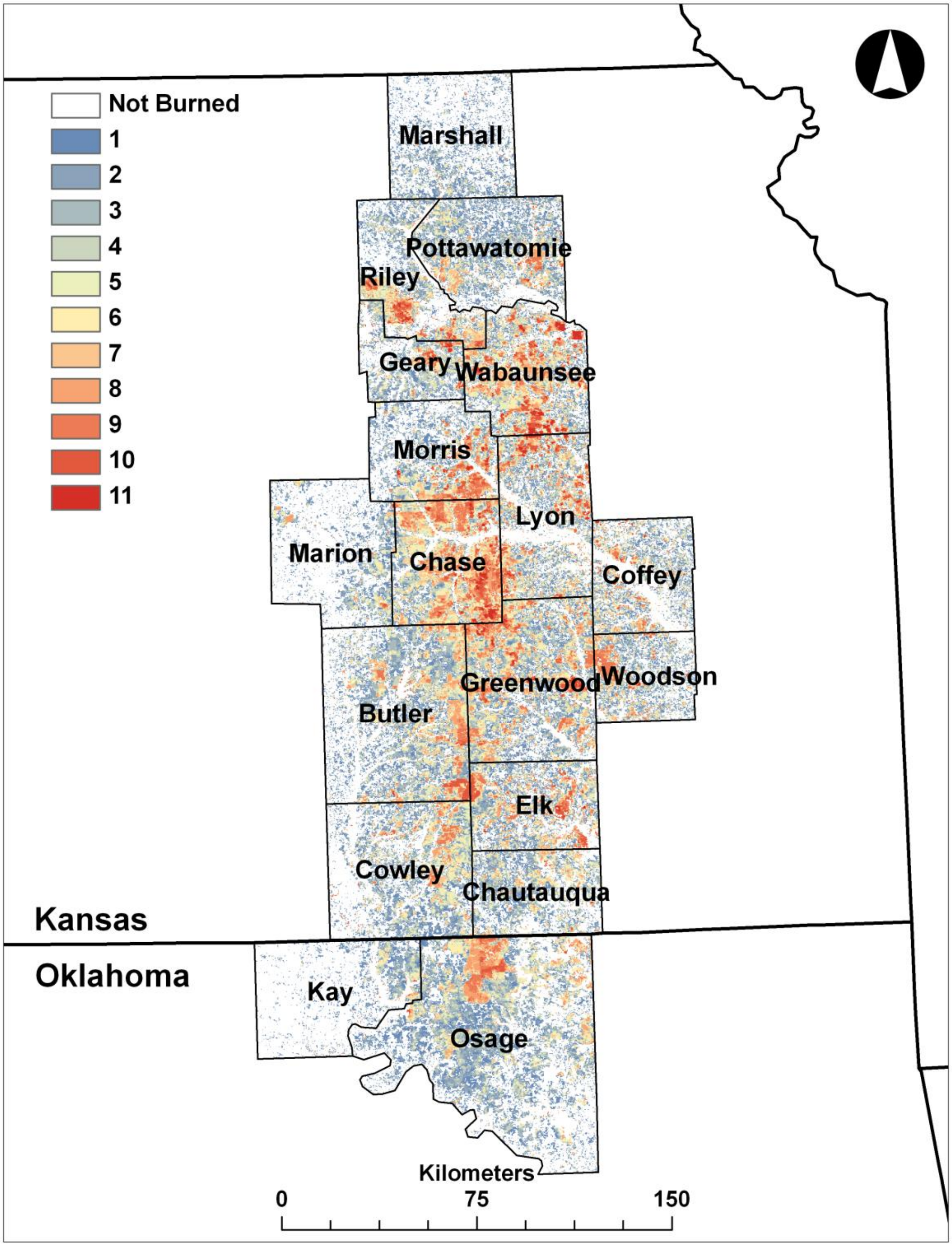


Figure 3-6. Flint Hills burn frequency, 2000-2010.

Table 3-1. Cumulative burning statistics for 2000-2010.

Burn Frequency (years)	Total burned (acres)	Percent burned
1	1,037,195	15
2	857,532	12
3	754,212	11
4	643,353	9
5	565,639	8
6	501,161	7
7	425,036	6
8	380,141	6
9	296,311	4
10	151,228	2
11	60,340	1

A paradigm to enhance heterogeneity in order to promote biological diversity and wildlife habitat on rangelands was proposed by Fuhlendorf and Engle (2001). One management practice used to enhance heterogeneity is patch-burn grazing (PBG). This fire-induced grazing regime is designed to approximate the natural interaction between fire and grazers. Typically, one-third of a PBG pasture is burned each year on a rotational basis. When only a portion of a pasture is burned, livestock focus most of their grazing in the burned patches. The result is an accumulation of vegetation in unburned areas, creating wildlife habitat and fuels for fires in subsequent years. The interaction of these disturbances produces a shifting mosaic of vegetative structure. PBG has been suggested as a way to reduce smoke emissions in the Flint Hills. One study (Rensink, 2009) indicates that less biomass would be consumed annually by fire when a pasture was managed with patch burning compared to the entire pasture being burnt annually. However, its effectiveness for smoke reductions remains an open question. Even though only one-third of a pasture is burned each year under PBG management, two years of growth with minimal grazing is also being consumed in the burned patch. It is also important to recognize that some pastures in the Flint Hills may not be well suited to PBG because of the difficulty of maintaining fire breaks, and that the practice may require additional resources (fire equipment and manpower) to implement. PBG is also viewed by some as experimental, and may require additional research before it becomes a widely accepted practice.

Debate will continue regarding when and how often to burn tallgrass prairie; however, there is wide scientific consensus supporting the need for prescribed fire in native grasslands. One of the greatest threats to the tallgrass region is forestation due to fire suppression. Eastern red cedar, a species readily controlled with fire when trees are small, is rapidly increasing in coverage in Kansas, especially in the eastern half of Kansas. Red cedar and other invasive plant species targeted with herbicides can be managed more economically and with fewer ecologically impacts using prescribed fire.

Until only recently, certain areas of the Flint Hills, especially along the eastern and western flanks of the Flint Hills (e.g., southeastern Greenwood County), lacked a fire culture and seldom burned. As a result, many of these areas experienced heavy encroachment by woody vegetation, and are no longer able to support interior grassland species like greater prairie-chickens. At Konza Prairie, annual burning was the only fire treatment that reduced woody plant density, with rapid increases in woody encroachment for longer (≥4-year) fire-return intervals. Therefore, pastures with a high density of woody vegetation may need higher fire frequency than is currently practiced to reverse years of fire suppression. Annual burning may be less warranted in areas of the Flint Hills where woody vegetation is not a significant problem. Conversely, areas not receiving enough fire to keep ahead of woody encroachment may require burning consecutive years to reverse this trend. In the Flint Hills of Kansas, prescribed fire is used by management actions to meet specific resource objectives that are designed to preserve and restore the essential ecological processes of fire. Fire frequency may vary depending on the natural resource objective to be met, depending on the degree of preservation, restoration, invasive species (pest) control, or reducing the risk of damaging wildfires. The Kansas Flint Hills is a unique ecosystem that is highly dependent on a frequent fire return interval to maintain and sustain the native species composition of the tall grass prairie.

The fire return interval of the Flint Hills landscape must remain frequent to mimic fire under natural conditions and support the continuation of the wildland prairie ecosystem. Research shows that historically, the natural fluctuation of fire (i.e. the natural fire return interval) of a tall grass ecosystem averaged every 2- 5 years. Data show that on average, prescribed fire is applied to approximately 1/3 of the tall grass prairie every year. While some lands within this vast ecosystem may burn almost every year others may burn every 5 years or less, depending on a number of uncontrollable variables such as precipitation, temperature and flora growth. However, one can use these average numbers to make two general interpretations, (1) prescribed fire is used roughly once every 3 years in the Flint Hills and (2) this fire frequency mimics the natural fire return interval for this ecosystem dating back hundreds of years. In fact, through research and practice, it has been proven that lower frequencies of burning will lead to a loss of the ecosystem in only a matter of a few burn cycles.

This evaluation demonstrates that the likelihood of prescribed fire recurrence is within the range of the natural fire return interval established historically for the tall grass prairie ecosystem and thus meets the ‘‘unlikely to recur at a particular location’’ requirement of the statutory language.

3.3 Alternative Management Practices

In order to preserve the remaining tallgrass prairie in the Flint Hills, it is imperative that invasive species be controlled. The primary invasive species of concern in this region include trees (osage orange, eastern red cedar, honey locust), brush (sumac, buckbrush) and plants (*sericea lespedeza*). To control these invasive species, farmers or ranchers often use chemical, mechanical, and/or burning-based methods to stop the intrusion of these invasive species. These methods are used in combination depending on the size of the acreage being managed. The following is a detailed discussion of each of these methods and the costs associated with implementing them.

3.3.1 Chemical Treatment

Chemical treatment refers to the application of specific chemicals that can eliminate various invasive species. Triclopyr, Metsulfuron, Picloram, Fluroxypry, and 2,4-D are common chemicals used for the invasive species listed above. These chemicals, individually or in mixtures, can be applied to an area by spraying each individual invasive species of interest with a handheld sprayer, using a vehicle with an attached tank that sprays chemical solution at a specific rate, or by an airplane that can spray a chemical solution as it flies over a field containing these invasive species. How often a field is treated depends on how difficult it is to control the invasive species and how prevalent they are within an area.

The costs of each of chemical treatment methods can vary greatly, with the primary influences being labor and the chemicals used. Using a handheld sprayer is not a practical method for large fields or for larger trees. Custom work using a vehicle with an attached sprayer costs from $5 to $9 per acre, depending on the difficulty of the terrain. Aerial application of herbicides costs from $7 to $9 per acre depending on the distance to the field to be treated from the airport. Adding in the cost of the chemicals used for treatment can increase the costs substantially with total chemical treatment costs ranging from $20 to $90 per acre to spray for combinations of invasive species, without considering the costs needed to eliminate eastern red cedars.

In addition to labor and chemical costs, it is important to recognize the advantages and disadvantages associated with using chemical treatments to rid an area of various invasive species. Chemical treatments can attack multiple invasive species with one application and are effective against new and small invasive plants. However, complete removal of dead invasive species may require additional methods and labor, different soil types require different amounts of chemicals to be effective, and the application of chemicals for individual trees is not practical for large fields with numerous trees. Any form of chemical treatment also includes the risk of impacts on non-target species as well as possible impacts on surface and ground water.

3.3.2 Mechanical Removal

Mechanical removal methods involve using tools to physically remove the invasive species from a given area. Tools used for this process can vary from a simple handsaw, to a small skid-steer, to multiple bulldozers dragging chains over a large field. Mechanical removal methods are primarily used to control the eastern red cedar trees in the Flint Hills; thus, this section will only focus on removal costs for this species. Tree growth is dependent on the type of tree and how much moisture the tree receives, but it is recommended that these trees be controlled before they reach three feet tall, which can happen within a matter of a few years.

The Oklahoma Cooperative Extension Service recently performed a study on eastern red cedar removals in the state of Oklahoma and included mechanical costs for this process. The study concluded that for fields larger than 640 acres, which are common throughout the Flint Hills, prescribed burning methods were recommended for small and moderates sized cedar trees with no alternative mechanical methods listed. For fields smaller than 640 acres, mechanical removal costs were in the same price range as those for chemical treatment depending on the method used.

Mechanical methods are generally the only option available for larger trees and are good at reducing seed production. That being said, mechanical methods use large equipment for removals that can cause severe damage to an area (both physically and ecologically), are not suitable for steep slopes or rocky terrain, must be done repeatedly to exhaust the seed bank in the soil, can require additional steps to remove the downed trees (such as prescribed burning), and sometimes requires chemical treatments to completely kill species such as osage orange and honey locust.

3.3.3 Prescribed Burning

Because the tallgrass prairie area provides natural fuel necessary for fires when moderately dry, burning is another method that can provide a means of eliminating invasive species. When weather conditions are prime (i.e., not overly windy nor wet), a fire is started in a location such that the path of the prescribed burning is optimized by the wind direction, which helps the fire spread through an entire field until the fire either runs out of fuel/tallgrass prairie or is manually extinguished. When a prescribed fire occurs in a relatively large area, a larger work crew is needed to monitor this event. Typically a crew monitoring a prescribed fire uses all-terrain or utility vehicles to follow the path of a fire with a pumping system that can extinguish a fire if it gets out of hand. Custom burning prices can vary from $6 per acre for a relatively flat, large pasture to upwards of $20 per acre for complex, small fields.

Beyond cost estimates for prescribed burning, there are several pros and cons associated with this method. Prescribed burning is cost effective, preserves the natural ecosystem that has adapted to regular pasture burnings, improves access to an area, reduces hazardous fuel levels that could feed intense fires if continually accumulated, and improves wildlife and livestock habitat by replenishing nutrients in the soil. Prescribed fires may not completely remove large trees from a field, and can raise safety concerns with a fire intruding on other people’s property or roads.

3.4 Conclusions

Controlling invasive species that were historically controlled by wildfires or prescribed fires set by Native Americans is critical to preserving the tall grass prairie ecosystem. Although chemical and physical control methods exist, they tend not to be practical for the large acreages involved and they are more expensive per acre. In addition to this, chemical and mechanical methods are often used concurrently with each other, thus increasing the cost and labor even more. Chemical and mechanical methods also cause more harm to the ecosystem than burning. Burning does a much better job of maintaining the ecosystem in its historical state then physical or chemical control methods. Prairie fires have been happening for centuries in the Flint Hills, and the local ecosystem has adapted to this regimen.

In summary,

- to maintain and preserve the ecological integrity of tallgrass prairie, prescribed fire is a necessary management tool. Both plant and animal species depend on the positive effects of burning. Failure to regularly burn the Flint Hills will result in increasing losses of what remains of this last landscape of tallgrass prairie and will quickly turn the Flint Hills area into a Cedar forest.

- Present fire frequencies in the Flint Hills are consistent with the historic natural fire return interval.
- prescribed fires can often be planned and executed in a way that minimizes downwind impacts as compared to fires that might otherwise occur naturally or accidentally.
- prescribed fires can often be planned and executed in a way that prevents catastrophic property damage or health impacts that might otherwise occur with uncontrolled fires.
- many of these fire-dependent ecosystems cannot maintain or sustain natural species composition without fire.
- controlled burning reduces fuel loads and encroachment of woody vegetation.
- fire is a likely eventual outcome in these ecosystems; suppressing such fires may ultimately lead to catastrophic wildfires in areas where eastern red cedars occur on the perimeter of cities such as Manhattan, Topeka and Emporia.

4. Causal Relationship

4.1 Summary of Results

This section demonstrates a causal relationship between the smoke due to local and regional fires and the 8-hour ozone concentrations above 0.075 ppm that occurred in Kansas on April 6, 12, 13, and 29, 2011. In particular, this section provides evidence that (1) smoke from biomass burning can enhance the formation of ozone; (2) smoke from Flint Hills and other regional fires was transported to the impacted monitors on the days when 8-hour ozone concentrations were above 0.075 ppm; and (3) the smoke enhanced ozone formation at specific monitors, resulting in 8-hour ozone concentrations above 0.075 ppm. This evidence includes discussion of fire locations, meteorological conditions, satellite observations of smoke, smoke transport, and air quality data on the four days when 8-hour ozone concentrations were above 0.075 ppm.

Meteorological and air quality data suggest that the 8-hour ozone concentration(s) exceeding the NAAQS in Kansas were very likely caused by

- smoke from fires in the Flint Hills on April 6, 12, and 13, 2011 (based on fire locations relative to the impacted monitors, wind patterns favorable for transport of smoke to the impacted monitors, and reduced visibilities with smoke and/or haze reported in the vicinity of the impacted monitors); and
- smoke from fires in Texas and Mexico on April 29, 2011 (based on wind patterns favorable for long-range transport of smoke to the impacted monitors).

4.2 Literature Review Providing Evidence that Biomass Burning Can Result in Elevated Ozone Levels

To establish a relationship between smoke from biomass burning and ozone enhancement, relevant scientific articles from peer-reviewed journals were collected and reviewed. The articles depicted a complex relationship between biomass burning and ozone formation and indicated several cases in which ozone concentrations exceeding the NAAQS were attributable to smoke from biomass burning.

Smoke from biomass burning contains a number of constituents, including ozone precursors such as nitrogen oxides (NO_x) and non-methane hydrocarbons (NMHCs) (McKeen et al., 2002; Jaffe et al., 2008). Previous observational studies have shown that smoke from biomass burning can enhance the formation of ozone under a variety of conditions (e.g., Hobbs et al., 2003; Junquera et al., 2005; Pfister et al., 2006). Ozone enhancement due to biomass burning is highly variable and depends on a number of factors, including fuel type, combustion efficiency, and available solar radiation (Jaffe and Wigder, 2012). In addition, ozone enhancement associated with biomass burning can take place both immediately downwind of a fire and after long-range smoke transport. Junquera et al. (2005) found ozone enhancements of up to 60 ppb within 10 km of fires in eastern Texas. Using ozonesondes, Morris et al. (2006) found a 25–100 ppb increase in aloft ozone concentrations over Texas due to long-range transport of smoke from wildfires in Canada and Alaska. In the analysis of a November 2009 smoke plume in California, Akagi et al. (2012) found that “despite occurring approximately one month before the winter solstice, the plume was photochemically active and significant amounts of ozone formed within a few hours”, demonstrating that ozone enhancement due to smoke can take place in the cool season when ozone concentrations are typically lower. Conversely, in some cases, ozone concentrations were shown to be suppressed near wildfires, possibly because of thick smoke obstructing incoming UV radiation and/or titration of ozone due to high NO_x concentrations in the smoke plume (Bytnerowicz et al., 2010; Stith et al., 1981).

Previous studies have also shown that fires contributed to exceedances of the NAAQS for 8-hour ozone (Jaffe et al., 2004; Junquera et al., 2005; Bein et al., 2008). And, using photochemical model simulations, Pfister (2008) found 10–15 ppb increases in ozone near fires in Northern California over the September 1-20, 2007, period and near fires in Southern California over the October 15-30, 2007, period, concluding that “intense wildfire periods frequently can cause ozone levels to exceed current health standards.” In addition, the EPA recently agreed to a request from the California Air Resources Board (CARB) and the Sacramento Metropolitan Air Quality Management District (SMAQMD) to exclude exceedances of the NAAQS for 1-hour ozone concentrations due to emissions from biomass burning under the Exceptional Events Rule. In that case, CARB and SMAQMD used a weight-of-evidence approach similar to the approach used for this Exceptional Events demonstration—including analysis of air quality and meteorological data, satellite imagery, air parcel trajectories, and photochemical modeling—to show that smoke from wildfires in the summer of 2008 resulted in ozone exceedances in the Sacramento region (Sacramento Metropolitan Air Quality Management District, 2011).

4.3 Analysis Methods

Several analysis methods were used to assess whether the 8-hour ozone concentrations above 0.075 ppm were caused by smoke. Fire and smoke locations were analyzed in relation to the impacted monitors, and meteorological data were evaluated to determine whether conditions were favorable for transport of smoke from fires to the impacted monitors. Air quality data and visibility observations were used to assess whether smoke was present at the impacted monitors.

4.3.1 Existence of Fires and Other Unusual Emissions

For each event day, NOAA-HMS fire and smoke plume data were analyzed to determine the locations and spatial extent of the fires/smoke on the event days and to assess whether fires occurred upwind of the impacted air quality monitors. Geographic Information System (GIS) mapping was used to combine the NOAA-HMS data sets with visible satellite imagery to evaluate the locations of fires and dense smoke plumes in relation to the locations of air quality monitors.

Fire locations and extent were also assessed by examining daily burn estimates by county, provided by KDHE for April 4-16 and April 25-30, 2011 (**Table 4-1**). Daily burn acreage was estimated using the methodologies described below. The preferred method was to utilize

MODIS satellite imagery on days when clouds were not present to obstruct the image. The MODIS imagery was analyzed using ENVI software; this software is able to determine pixels representing the ground surface that have been burned by their red and near-infrared reflectance. This analysis was performed for the counties in the region comprising the Flint Hills. Pixels showing burned areas were identified and highlighted by their reflectance; the software then identified polygons with similar red and near-infrared reflectance values and designated those pixels as representing burned areas on a given day. The analyzed results from ENVI were then exported to ArcGIS. In ArcGIS, the burn results for each day were calculated by subtracting the burn analysis results from the previous day to ensure that the final results did not include double-counting. This method provided the most accurate data regarding burned acres.

For days when one or more cloudy days occurred after a clear day, KDHE staff used the ENVI program to determine the number of acres burned during the cloudy interval and then allocated the total number of acres burned over the cloudy period to each day. For these allocations, KDHE produced daily burn estimates using a proportion of acres burned in individual counties in each day, based on a cumulative total of acres burned over the cloudy period and analysis of the NOAA-HMS fire detects. KDHE also evaluated the weather conditions for the Flint Hills to determine whether burning was likely to have taken place during the cloudy days. Days when rain fell on all or part of the region were excluded as burn days. Days with high winds that would have made for hazardous burning conditions were also excluded. In addition, burn reports from county extension agents were used to supplement the acreage allocation decisions.

Table 4-1. Daily Flint Hills burn acreage estimates and data source for April 2011. Bold entries indicate dates with 8-hour ozone concentrations above 0.075 ppm in Kansas. The three days with largest burn acreage estimates (April 6, 12, and 13) were days on which 8-hour ozone concentrations were above 0.075 ppm.

Date	Acres Burned	Source
4/1/2011	43,997	SmartFire
4/2/2011	83,271	SmartFire
4/3/2011	21,656	SmartFire
4/4/2011	1,829	KDHE
4/5/2011	142,982	KDHE
4/6/2011	**248,358**	**KDHE**
4/7/2011	34,469	KDHE
4/8/2011	178,071	KDHE
4/9/2011	84,244	KDHE
4/10/2011	7,133	KDHE
4/11/2011	136,975	KDHE
4/12/2011	**298,243**	**KDHE**
4/13/2011	**291,296**	**KDHE**
4/14/2011	58,259	KDHE
4/15/2011	185	KDHE
4/16/2011	233,036	KDHE
4/17/2011	27,373	SmartFire
4/18/2011	23,284	SmartFire
4/19/2011	2,134	SmartFire
4/20/2011	17,094	SmartFire
4/21/2011	613	SmartFire
4/22/2011	5,624	SmartFire
4/23/2011	1,500	SmartFire
4/24/2011	944	SmartFire
4/25/2011	110	KDHE
4/26/2011	3,207	KDHE
4/27/2011	880	KDHE
4/28/2011	139,697	KDHE
4/29/2011	**19,134**	**KDHE**
4/30/2011	13,104	KDHE

The SmartFire model was used to estimate daily burn estimates when estimates from KDHE were not available (April 1-3 and April 17-24). SmartFire combines multiple sources of fire information and reconciles them into a unified GIS database. SmartFire data sources include space-borne sensors and ground-based reports, thus drawing on the strengths of both data types while avoiding double counting.

To supplement the fire and smoke data described above, news stories regarding fires and smoke in April 2011 were acquired from credible media sources. Additionally, reports from the climate and wildfire reports were collected from the National Oceanic and Atmospheric Administration (NOAA) and the United States Forest Service (USFS). These reports can be found in **Appendix B**.

In addition, KDHE has reviewed media documents, and contacted local agency and KDHE district staff regarding the April days that are the subject of the exceptional event request and are unable to find any emergency conditions, other large local fires, or other anthropogenic events that occurred on the four days that would potentially cause the high ozone readings on the days in question.

4.3.2 Meteorological Conditions and Smoke Transport

Smoke transport, which refers to the movement of the smoke plumes, is important because the smoke plumes likely contained ozone and ozone precursors. Smoke transport was analyzed by reviewing surface wind observations and model air parcel trajectories.

For surface wind analysis, data from METAR sites nearest the impacted monitors were assessed. **Table 4-2** shows the pairings of air quality monitors to METAR sites used throughout this report to examine meteorological conditions near the air quality monitors. METAR sites were selected because of their known high data quality. In some locations, the nearest METAR site was located several miles from the impacted air quality monitor. However, meteorological conditions on the smoke event days were driven by large-scale patterns (e.g., regionally homogeneous). Thus, meteorological conditions observed at the METAR sites were likely very similar to conditions at the air quality monitors. In addition, no other reliable sources of meteorological data were available. Vector winds averaged over several hours were used in this analysis because they represent pollution transport better than scalar winds. These vector winds, along with other meteorological parameters (e.g., temperature), were evaluated with surface and upper-level observations, radar, and satellite maps to obtain a comprehensive view of the meteorological patterns on the days when 8-hour ozone concentrations were above 0.075 ppm.

Table 4-2. METAR sites used to represent meteorological conditions near air quality monitors with 8-hour ozone concentrations above 0.075 ppm.

Air Quality Monitors	METAR Site	METAR Site Location	Approx. Distance Between Air Quality and METAR Stations
Mine Creek[a]	KCNU	Chanute Martin Johnson Airport, Chanute, KS	50 miles
Peck	KICT	Wichita Mid-Continent Airport, Wichita, KS	12 miles
Wichita Health Dept.	KICT	Wichita Mid-Continent Airport, Wichita, KS	7 miles
Sedgwick	KICT	Wichita Mid-Continent Airport, Wichita, KS	18 miles
KNI-Topeka	KFOE KTOP	Forbes Field Airport, Topeka, KS Philip Billard Municipal Airport, Topeka, KS	6 miles 6 miles
Konza Prairie	KMHK	Manhattan Regional Airport, Manhattan, KS	5 miles

[a] Mine Creek is a rural site and has no nearby METAR station with quality-controlled data. KFSK (Fort Scott, 23 miles) is the nearest site with meteorological data, but historical data availability from that site is limited. KCNU was the closest meteorological station with weather conditions similar to those at Mine Creek on April 6, 2011.

Atmospheric soundings from KTOP (Topeka, Kansas) and KOUN (Norman, Oklahoma) were used to identify temperature inversions and stable layers. These features were assessed to determine whether smoke emitted at the surface remained in the lower levels of the atmosphere rather than mixing into aloft layers where it would not impact surface air quality monitors. Throughout April 2011, the atmospheric soundings frequently showed temperature inversion and stable layers, on days both with and without high ozone concentrations; thus, the presence of these features was not unusual, nor were they the reason for the high ozone concentrations observed on the smoke-event days. Confirming that the smoke would likely remain in the lower levels of the atmosphere by reviewing the soundings also provided guidance on which trajectory levels were appropriate to assess smoke transport.

AIRNow-Tech and the HYSPLIT model were used to create backward trajectories ending at each impacted monitor. AIRNow-Tech allows for easy visualization of several data sets, including air quality observations, meteorological data, fire and smoke data, and trajectories. Trajectories ending at 50, 100, and 500 m above the impacted monitors were modeled to show flow patterns throughout the surface-based mixed layer where smoke was likely present. Trajectory heights above the surface were also examined over the course of each trajectory path to determine whether smoke remained near the surface (e.g., near the impacted monitors). Trajectory images were created at two-hour intervals during the 8-hour window contributing to the 8-hour ozone concentrations above 0.075 ppm on the event days; the entire suite of trajectories created can be found in **Appendix C**.

4.3.3 Air Quality Conditions

Time-series of air quality and meteorological parameters were analyzed to assess the presence of smoke at the impacted monitors. Marked increases of ozone concentrations, in coincidence with similar increases in PM_{10} and $PM_{2.5}$ concentrations and decreases in observed visibility, may indicate the arrival of smoke in the vicinity of the impacted monitors. In addition, specific meteorological conditions (such as smoke, haze, or thunderstorms) reported at airports by human observers were considered.

4.4 Findings

This subsection contains the results of the causal relationship demonstration for the four days when 8-hour ozone concentrations were above 0.075 ppm. Fire and smoke locations, meteorological conditions and smoke transport, and air quality conditions are described for each day.

April 6, 2011

The results below demonstrate that ozone and ozone precursors in smoke plumes from fires in the Flint Hills caused the 8-hour ozone concentrations above 0.075 ppm at the Mine Creek, Peck, and Wichita Health Dept. monitors on April 6, 2011. Factors supporting this conclusion include:

- Numerous fires burning in the Flint Hills region.

- Low-level winds and model trajectories showing transport of smoke from fires to the impacted monitors.
- Reductions in visibility, increases in PM concentrations, and visual reports of smoke in coincidence with rapid increases in ozone concentrations at the impacted monitors.
- 8-hour ozone concentrations below 0.075 ppm at monitors that were not impacted by smoke.
- No other unusual emission sources that would have caused the high ozone concentrations.

Evidence of Fires

KDHE estimated that 248,358 acres burned on April 6 in the Flint Hills region; this is the third highest daily burn acreage estimate in April 2011. Fires were concentrated in the Flint Hills region, generally south of Topeka and east of Wichita, with additional fires extending further south near Tulsa, Oklahoma (**Figure 4-1**).

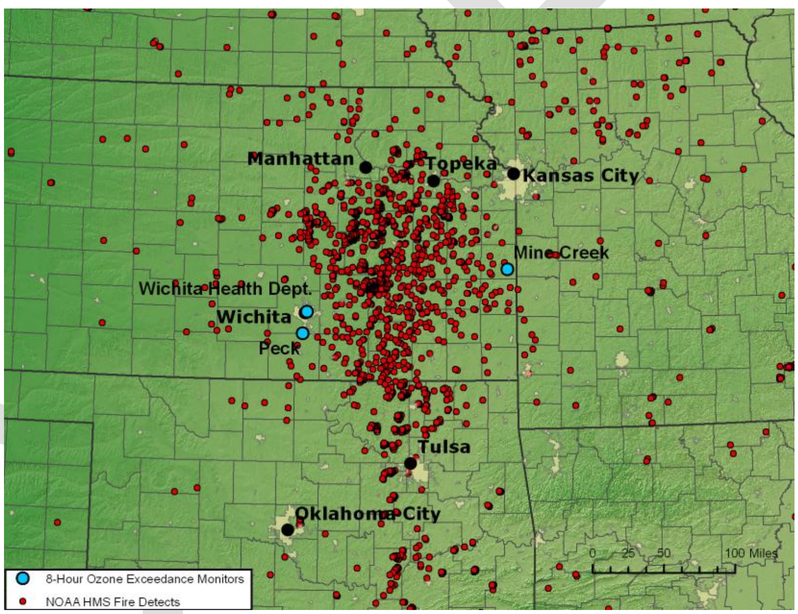


Figure 4-1. Fire locations on April 6, 2011, from NOAA-HMS. Numerous fires were detected in the Flint Hills region.

Meteorological Conditions and Smoke Transport

Meteorological conditions on April 6, 2011, indicated transport of smoke from fires in the Flint Hills to the impacted monitors. A weak 500 mb ridge of high pressure was located over the central United States. Upper-level ridges are generally associated with a stable atmosphere and reduced vertical mixing (**Figure 4-2**). At the surface, a low-pressure system was over Iowa and a cold front extended west-southwestward across central Kansas (**Figure 4-3**).

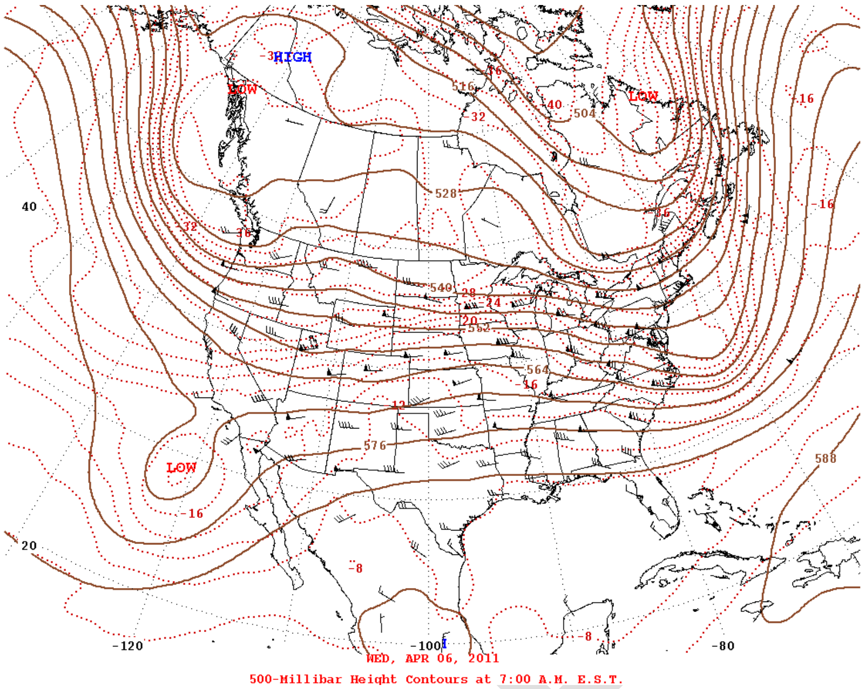


Figure 4-2. 500 mb heights at 06:00 on April 6, 2011, showing a weak ridge of high pressure over eastern Kansas. Source: NWS.

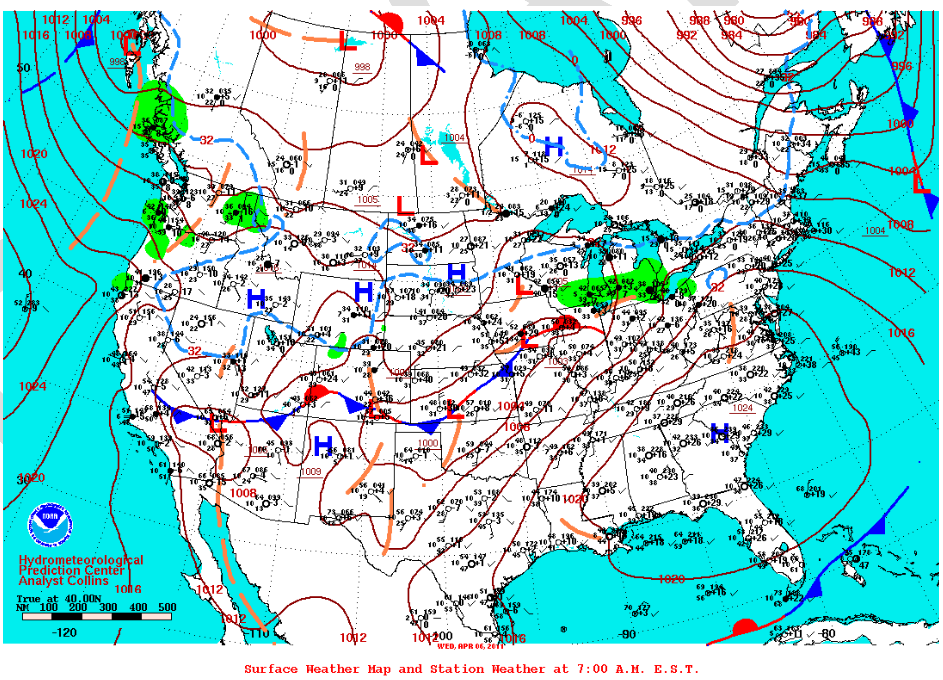


Figure 4-3. Surface weather map for 06:00 on April 6, 2011, showing a cold front over eastern Kansas, with southerly winds ahead and northerly winds behind the front. Source: NWS.

MODIS visible satellite imagery (**Figure 4-4**) and METAR observations indicated partly cloudy skies over eastern Kansas through the day. Satellite imagery also showed smoke in cloud-free areas over eastern Oklahoma and southeastern Kansas. The 06:00 KOUN sounding, representative of the pre-frontal air mass over Oklahoma and southeastern Kansas, showed a strong (approximately 7°C) temperature inversion from the surface to about 1100 m above ground level (AGL) (**Figure 4-5**). The inversion was strongest between 650 and 1100 m AGL, indicating that smoke emitted from the surface was likely trapped below that level.

At 06:00, the cold front was northwest of Wichita. Ahead of the front, winds were southerly at the three impacted monitors. As the cold front moved through the Wichita area at around 12:00, winds shifted from southerly to northerly (**Figure 4-6**), bringing air parcels into Wichita from the north and northeast, where they had passed through numerous fires (**Figure 4-7**). As the cold front approached the Mine Creek monitor, winds shifted from southerly to southwesterly, carrying air parcels that had passed through numerous fires over southeastern Kansas and northeastern Oklahoma. The trajectories remained below 100 m AGL while passing through the fire/smoke area, indicating that air parcels arriving at the receptor monitors were probably heavily impacted by the smoke.

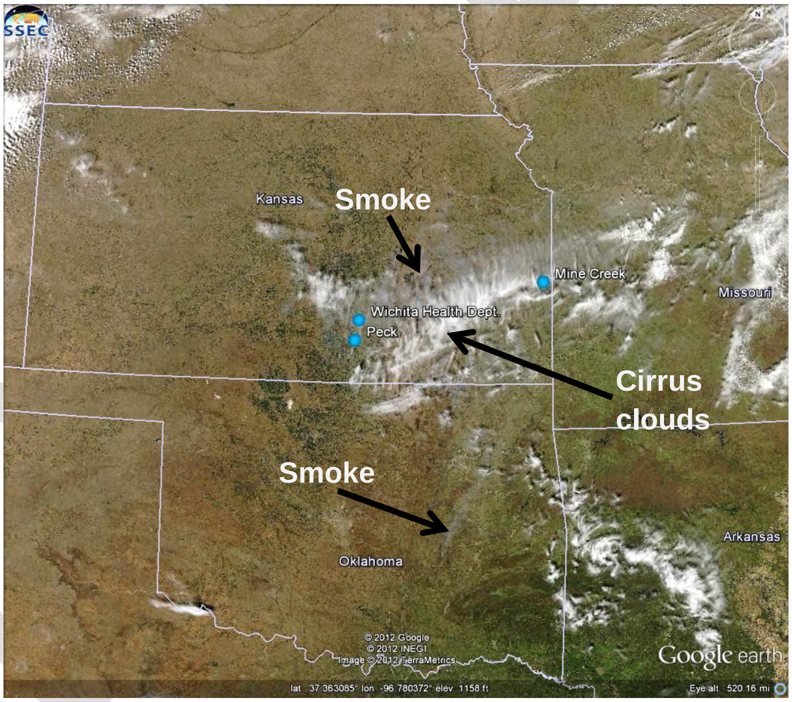


Figure 4-4. MODIS-AQUA visible satellite image from about 13:35 on April 6, 2011. Smoke is visible over east-central Kansas. Southeastern Kansas is obscured by cirrus clouds (white areas). Source: Space Science and Engineering Center (SSEC).

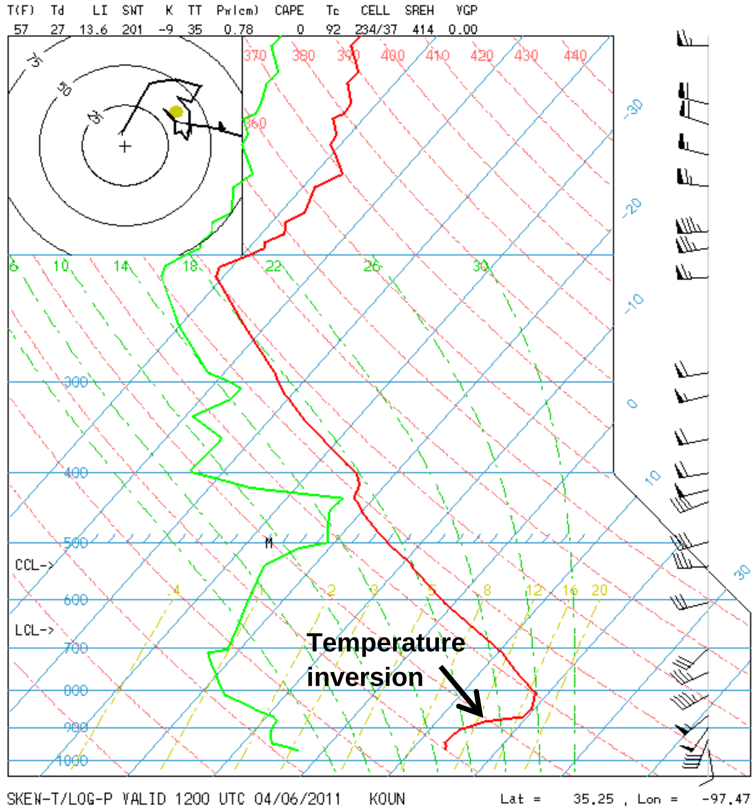


Figure 4-5. Radiosonde from KOUN at 06:00 on April 6, 2011, showing a strong temperature inversion near 650 m AGL, likely trapping smoke emitted at the surface beneath that level. Source: NWS.

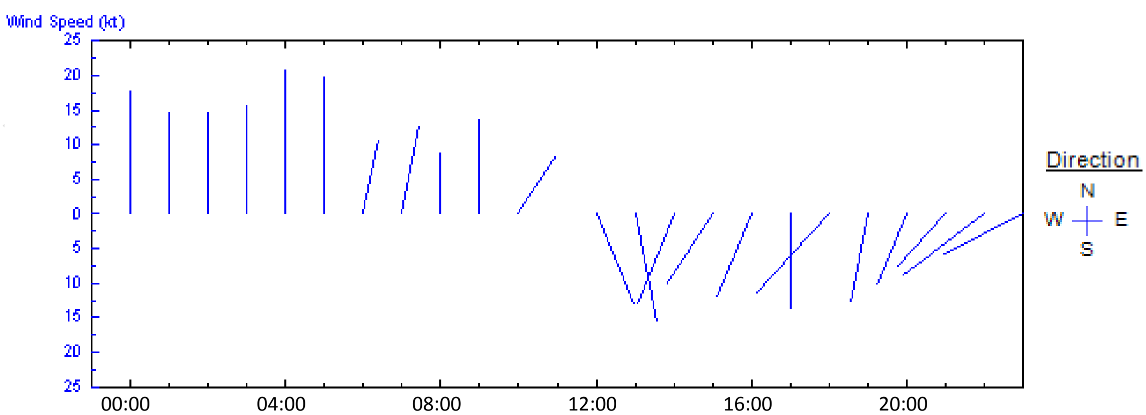


Figure 4-6. Hourly wind speed and direction at KICT on April 6, 2011. A distinct wind shift from southerly to northerly occurred with the cold frontal passage at 12:00. Lines point to direction in which wind is going.

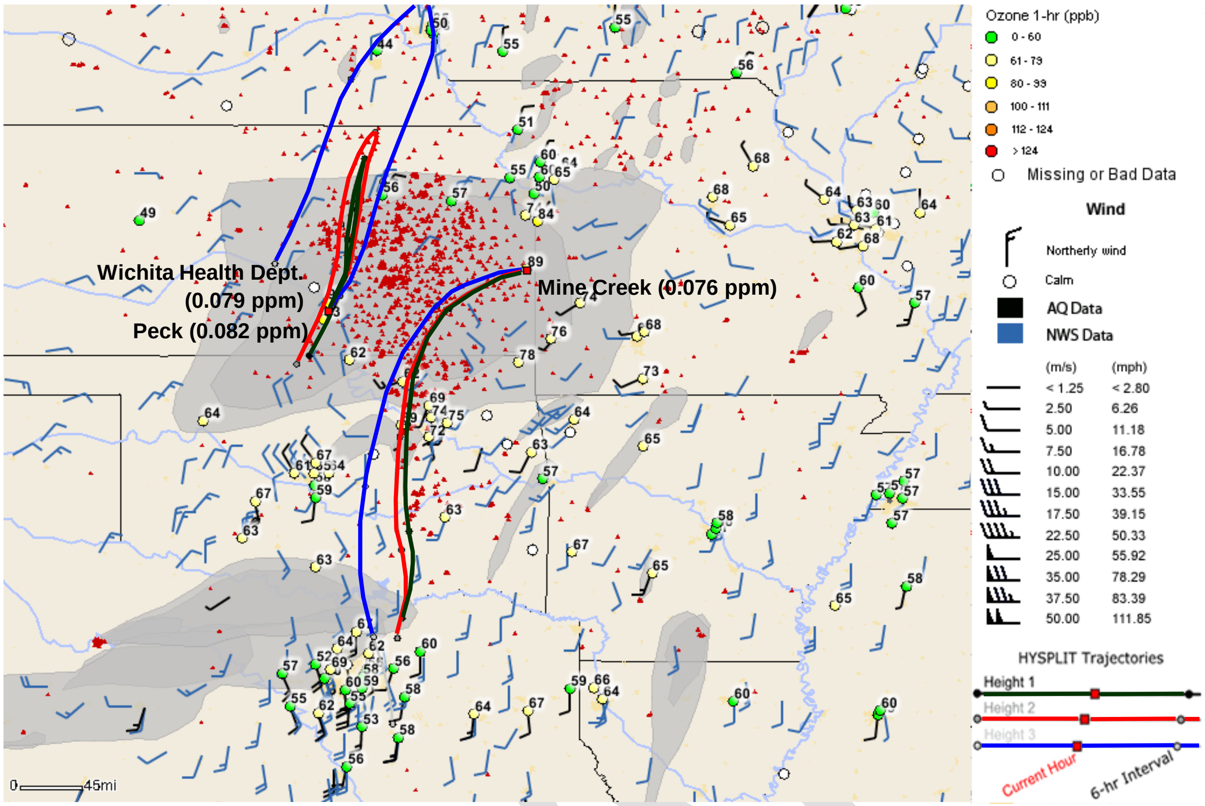


Figure 4-7. 24-hour backward HYSPLIT trajectories ending at 16:00 on April 6, 2011. For this and all similar trajectory plots, Height 1 = 50 m, Height 2 = 100 m, and Height 3 = 500 m, corresponding to ending height above the impacted monitor. Red dots and gray shading show cumulative daily fire and smoke locations, respectively. Southerly winds transported smoke to the Mine Creek monitor. Northerly winds transported smoke from the northern Flint Hills into the Wichita area monitors. Plot created in AIRNow-Tech.

Air Quality Conditions

$PM_{2.5}$ concentrations at the Mine Creek monitor (**Figure 4-8**) and PM_{10} concentrations at Wichita-area monitors (**Figure 4-9**) increased on the afternoon of April 6, coincident with the arrival of smoke shown by the trajectory analyses. Reports of smoke and haze with reduced visibility in Wichita coincided with higher PM_{10} concentrations, indicating that the higher PM_{10} concentrations were likely associated with smoke and not dust or other pollutants. When $PM_{2.5}$ and PM_{10} concentrations increased, ozone concentrations also increased rapidly at the impacted monitors (**Figures 4-8 and 4-10**), indicating enhancement of ozone production with the arrival of the smoke plumes.

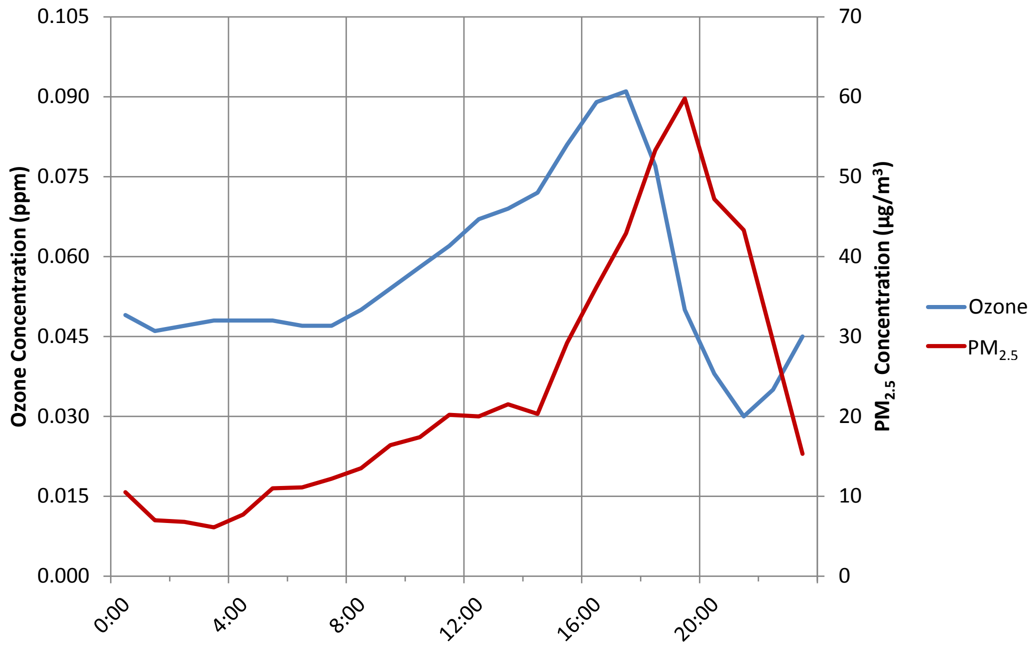


Figure 4-8. Hourly ozone and $PM_{2.5}$ concentrations at Mine Creek on April 6, 2011. Ozone and $PM_{2.5}$ concentrations both increased rapidly at 15:00, likely indicating the arrival of smoke.

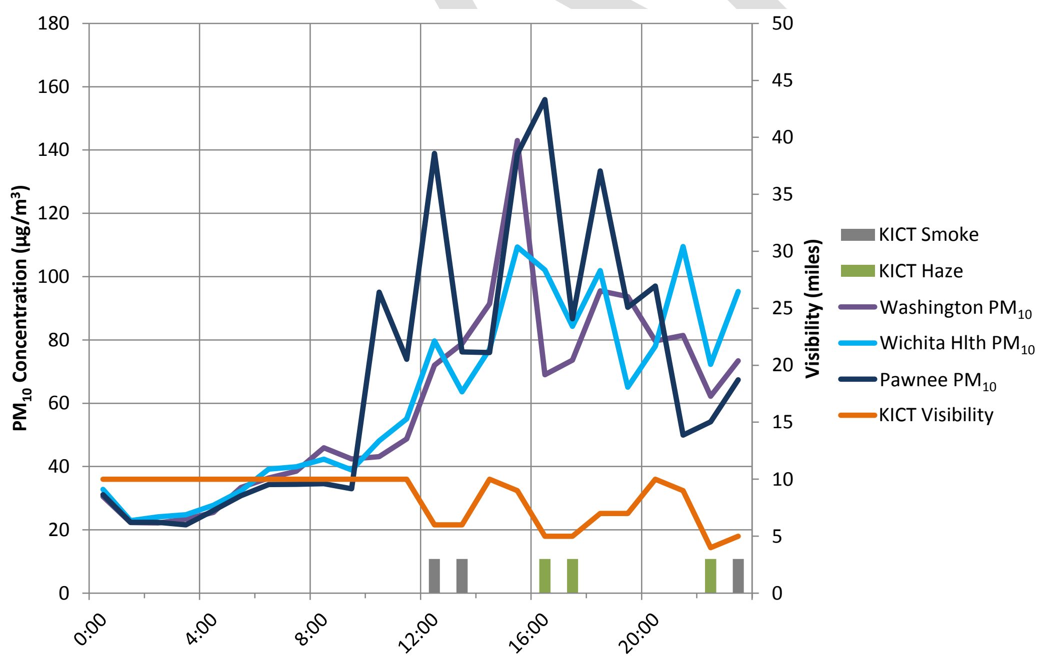


Figure 4-9. Hourly PM_{10} concentrations (left axis) and visibility (right axis) at Wichita area monitors on April 6, 2011. Grey and green bars at bottom of chart indicate hourly reports of smoke and haze, respectively, by KICT airport observers. PM_{10} concentrations increased rapidly in coincidence with reductions in visibility and reports of smoke and haze, indicating the arrival of smoke.

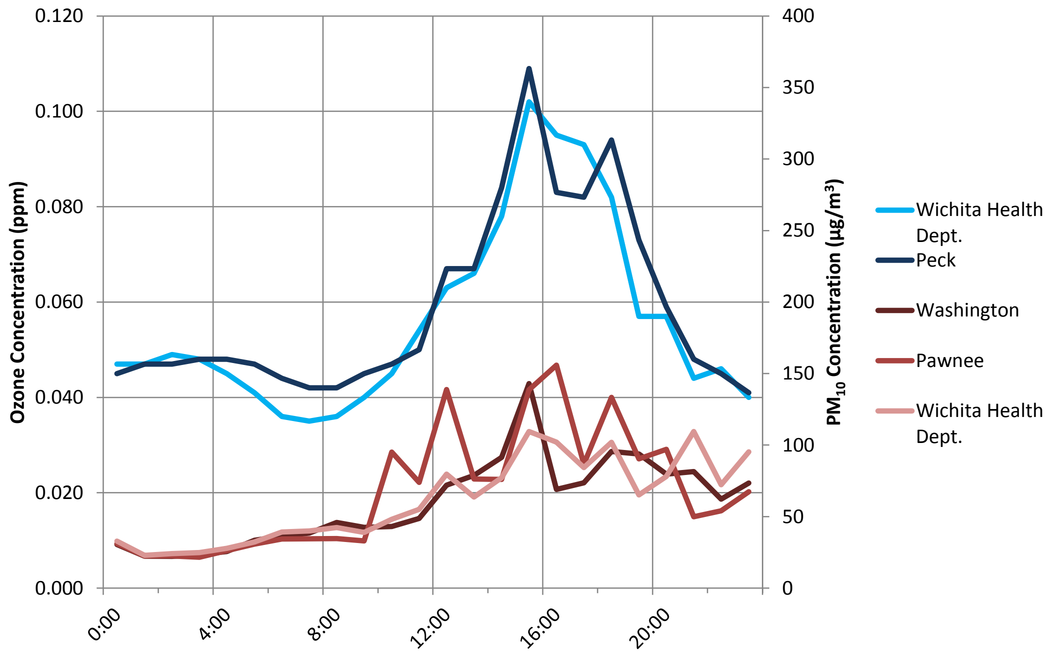


Figure 4-10. Hourly ozone (blue colors, top two lines) and PM_{10} (red colors, bottom three lines) concentrations at Wichita area monitors on April 6, 2011. Ozone and PM_{10} concentrations increased rapidly at 12:00 in the Wichita area, coincident with passage of a cold front and arrival of smoke from the north.

April 12, 2011

The results below demonstrate that ozone and ozone precursors in smoke plumes from fires in the Flint Hills caused the 8-hour ozone concentrations above 0.075 ppm at the KNI-Topeka and Konza Prairie monitors on April 12, 2011. Factors supporting this conclusion include

- Numerous fires burning in the Flint Hills region.
- Low-level winds and model trajectories indicating recirculation and transport of smoke from fires to the impacted monitors.
- Reductions in visibility, increases in PM concentrations, and visual reports of smoke in coincidence with rapid increases in ozone concentrations at the impacted monitors.
- 8-hour ozone concentrations below 0.075 ppm at monitors that were not impacted by smoke.
- No other unusual emission sources that would have caused the high ozone concentrations.

Existence of Fires

Fires on April 12, 2011, were concentrated in the Flint Hills region from northeastern Oklahoma northward across Kansas and surrounding the impacted monitors (**Figure 4-11**).

KDHE estimated that 298,243 acres burned on April 12; this is the highest daily burn acreage estimate in April 2011.

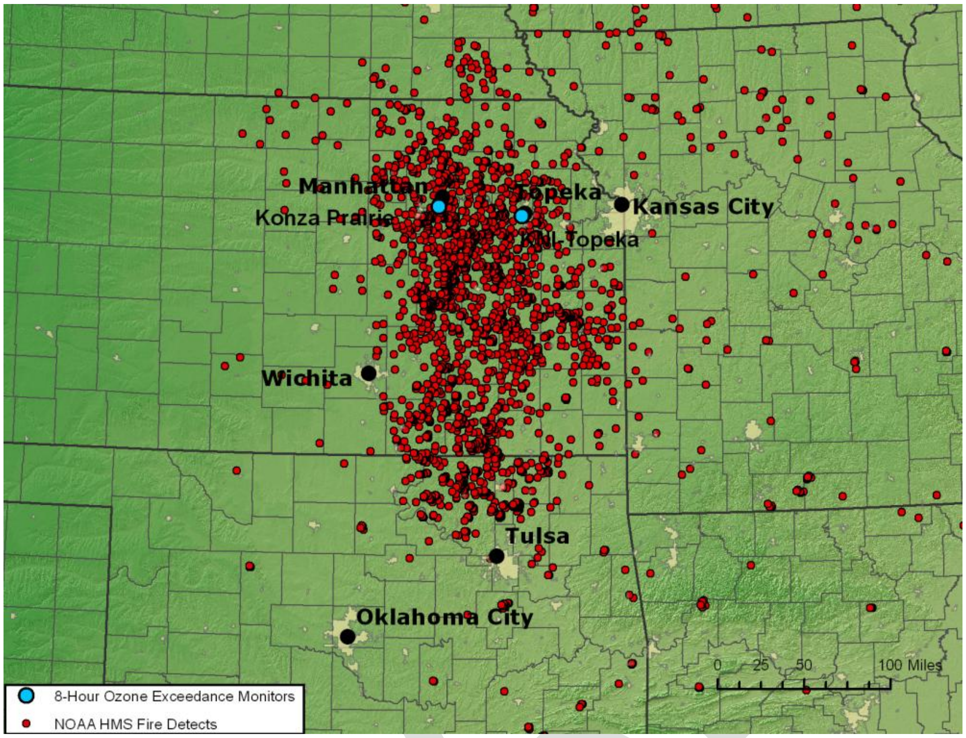


Figure 4-11. Fire locations (red dots) on April 12, 2011, from NOAA-HMS. Numerous fires were detected in the Flint Hills region near the impacted monitors.

Meteorological Conditions and Smoke Transport

Meteorological conditions on April 12, 2011, promoted the recirculation and transport of smoke from fires in the Flint Hills to the impacted monitors. Aloft, a ridge of high pressure was located over the central United States; aloft high pressure ridges are normally associated with reduced vertical mixing (**Figure 4-12**). At the surface, a broad high-pressure system over the central and southern Plains resulted in light winds across eastern Kansas during the overnight and morning hours (**Figure 4-13**). In the afternoon, the surface high gradually shifted eastward, resulting in light-to-moderate southerly winds across eastern Kansas. As shown by visible satellite imagery and area METAR observations, skies were clear across eastern Kansas for most of the day, with a few mid- and high-level clouds approaching from western Kansas (**Figure 4-14**). Visible satellite imagery showed extensive smoke over the Flint Hills region; the smoke was moving northward across the impacted monitors.

Atmospheric stability conditions on April 12 indicated that smoke would likely remain trapped near the surface. The 06:00 KTOP sounding (**Figure 4-15**) showed a strong (approximately 10°C) temperature inversion from the surface to nearly 300 m AGL; this inversion was due to cool overnight temperatures caused by clear skies and light winds. In addition, a subsidence inversion was located near 1400 m AGL. These inversions indicated that smoke would initially remain trapped near the ground. The 18:00 KTOP sounding

(**Figure 4-16**) showed that although surface heating under sunny skies had ended the surface inversion, a subsidence inversion remained near 1700 m AGL; smoke emitted at the surface was likely contained in the surface-to-1700 m AGL layer (and was not mixed above that level).

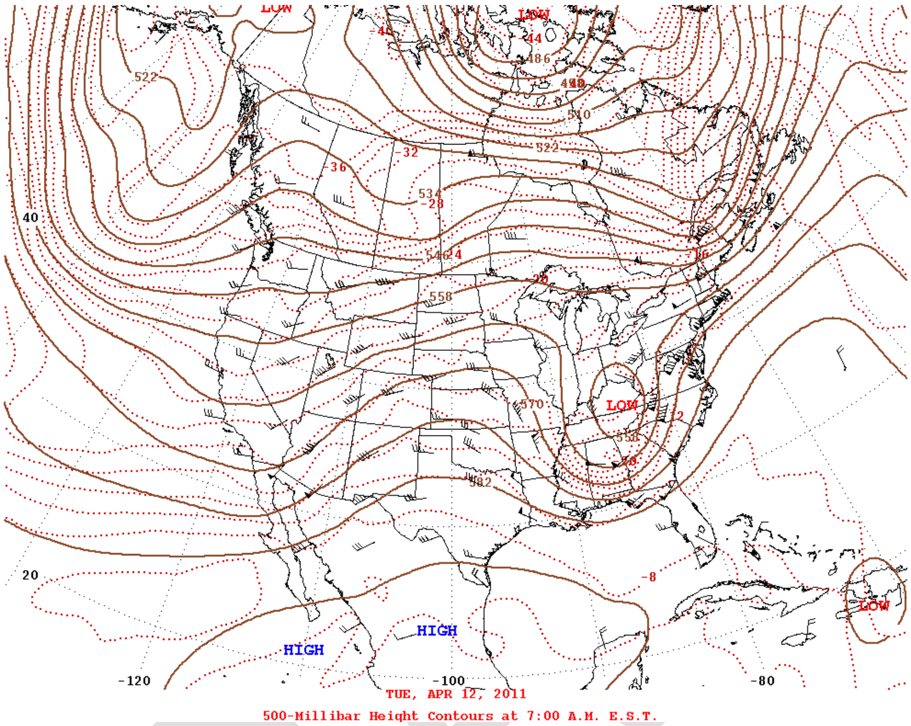


Figure 4-12. 500 mb heights for 06:00 on April 12, 2011, showing a ridge of high pressure over eastern Kansas, indicating reduced vertical mixing. Source: NWS.

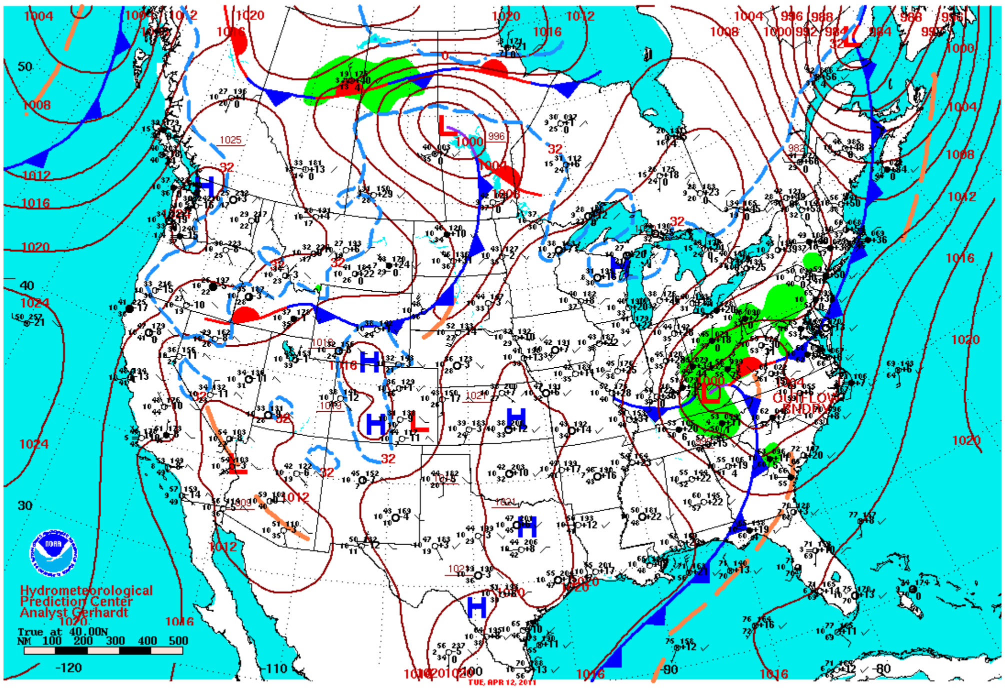


Figure 4-13. Surface weather map for 06:00 on April 12, 2011, showing high pressure with light winds over eastern Kansas. Source: NWS.

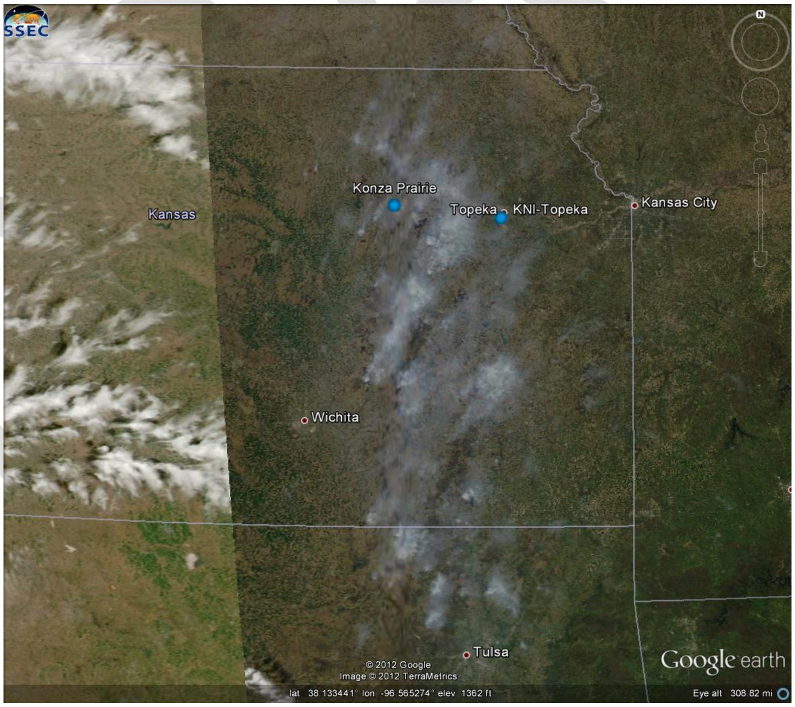


Figure 4-14. MODIS-AQUA visible satellite image from about 13:35 on April 12, 2011. Smoke is visible over the Flint Hills region impacting Konza Prairie and KNI-Topeka. Source: SSEC.

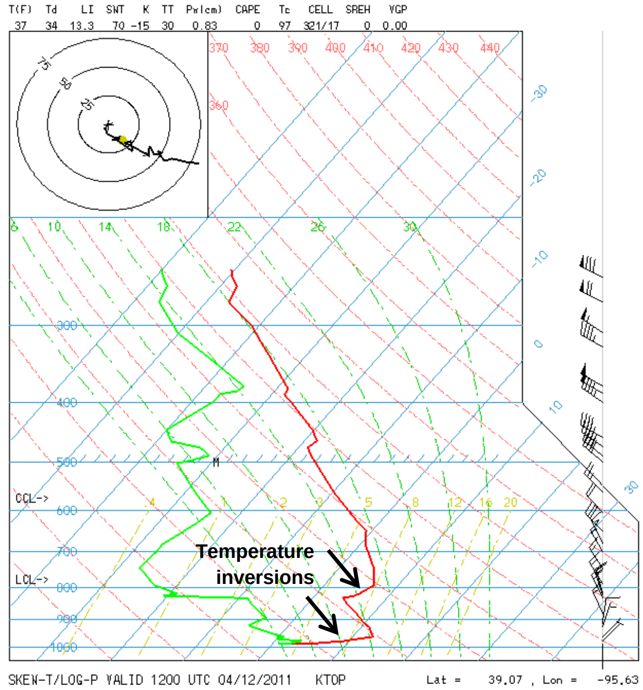


Figure 4-15. Radiosonde from KTOP at 06:00 on April 12, 2011. A strong temperature inversion near the surface indicates very limited vertical mixing during the morning of April 12. Source: NWS.

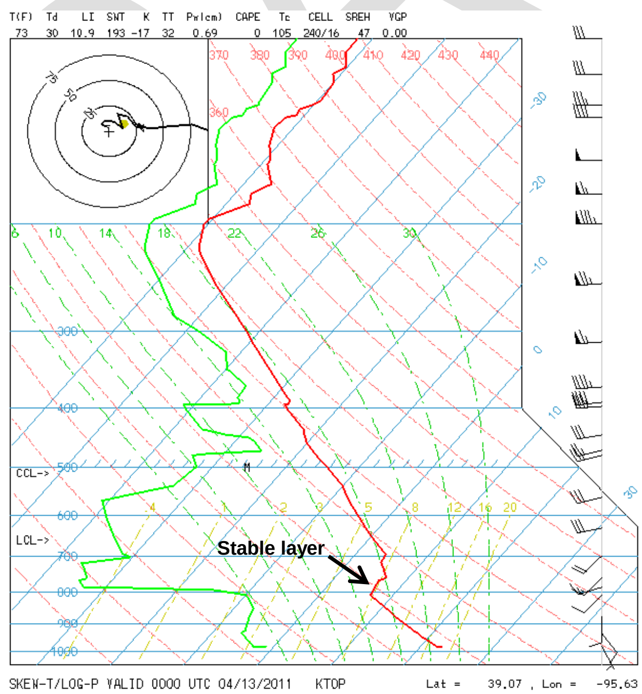


Figure 4-16. Radiosonde from KTOP at 18:00 on April 12, 2011. A stable layer above 800 mb likely confined smoke emitted at the ground in the surface-to-1700 m AGL layer. Source: NWS.

As winds gradually increased from the south across eastern Kansas (**Figure 4-17**), trajectories ending at the impacted monitors showed recirculation and indicated that air parcels spent several hours of residence time over the numerous fires in the Flint Hills region (**Figure 4-18**). The trajectories also remained below 100 m AGL while passing through the fire/smoke area. It is important to note that similar trajectories ending at Wichita and Kansas City area monitors did not pass through the region of widespread fires and smoke and that those monitors did not record 8-hour ozone concentrations above 0.075 ppm.

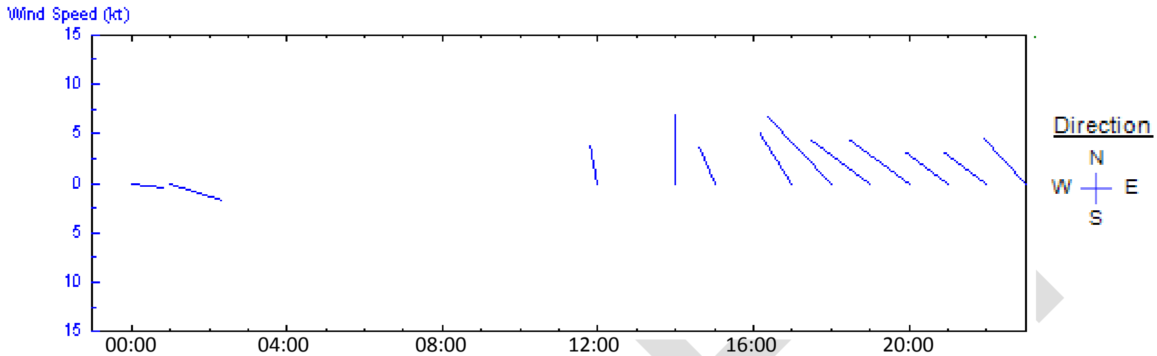


Figure 4-17. Hourly wind speed and direction at KTOP on April 12, 2011. Winds were calm for most of the overnight and morning hours; light southerly winds in the afternoon transported smoke to the impacted monitors. Lines point to direction in which wind is going.

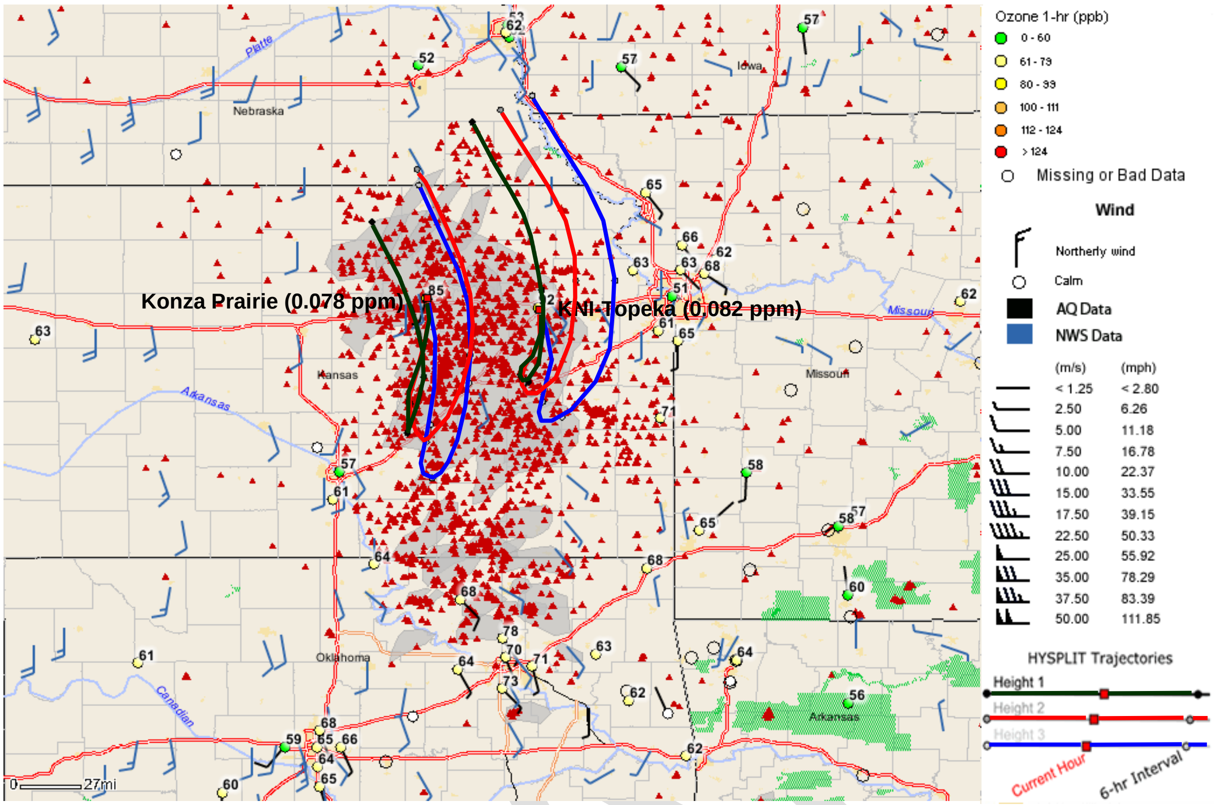


Figure 4-18. 24-hour backward HYSPLIT trajectories ending at KNI-Topeka and Konza Prairie sites at 16:00 on April 12, 2011. Northerly winds the previous day diminished overnight and switched to southerly during the day, resulting in recirculation and transport of smoke to the impacted monitors. Plot created in AIRNow-Tech.

Air Quality Conditions

PM_{10} concentrations at Topeka (**Figure 4-19**) increased rapidly after 13:00 on April 12, coincident with the arrival of smoke-influenced air shown by the trajectory analysis and visible satellite imagery. Smoke and haze with reduced visibilities were also reported at KTOP and KMHK around 14:00 on April 12 (**Figure 4-20**), indicating that the higher PM_{10} concentrations were associated with smoke and not dust or other pollutants. At KNI-Topeka, ozone and PM_{10} concentrations peaked at 17:00 (**Figure 4-21**), and at Konza Prairie ozone concentrations peaked at 14:00, when smoke was reported and visibilities were rapidly reduced.

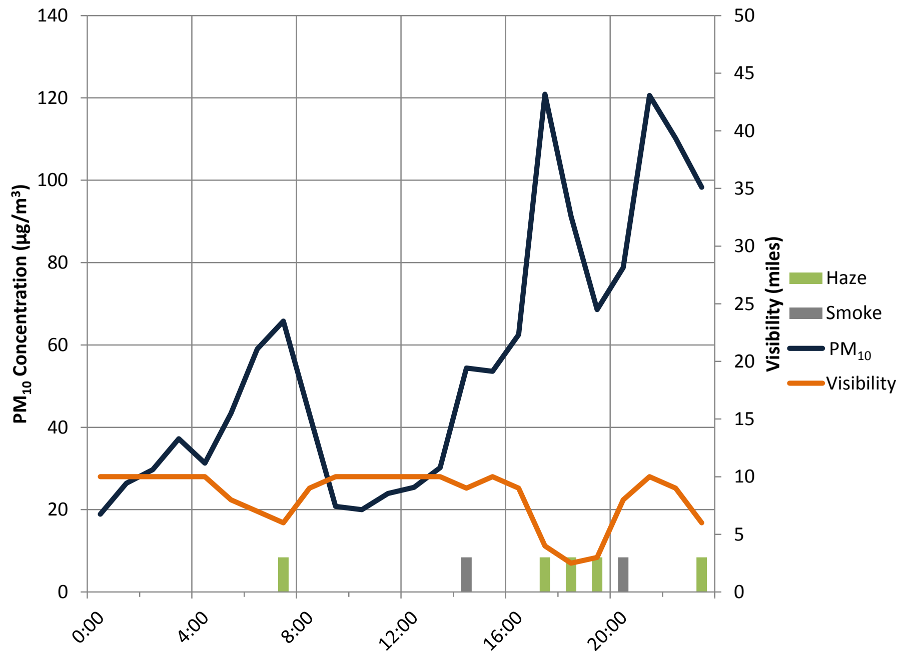


Figure 4-19. Hourly PM_{10} concentrations and visibility at Topeka on April 12, 2011. Increases in PM_{10} concentrations were coincident with decreases in visibility and reports of smoke, indicating the arrival of smoke at Topeka.

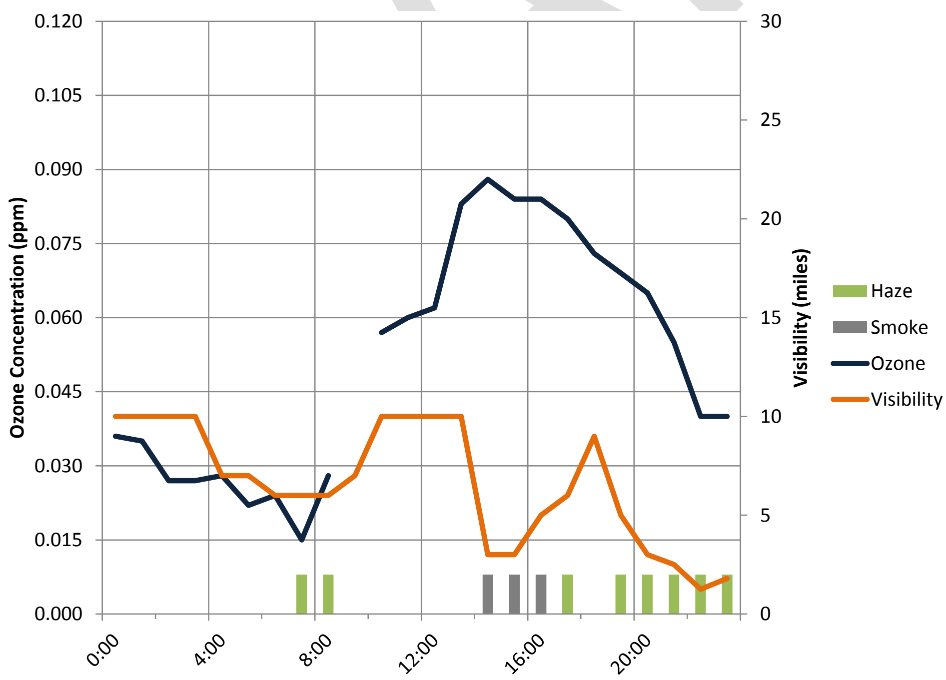


Figure 4-20. Hourly ozone concentrations at Konza Prairie and visibility at KMHK on April 12, 2011. Ozone concentrations increased rapidly after 12:00, coinciding with decreases in visibility and reports of smoke, indicating the arrival of smoke.

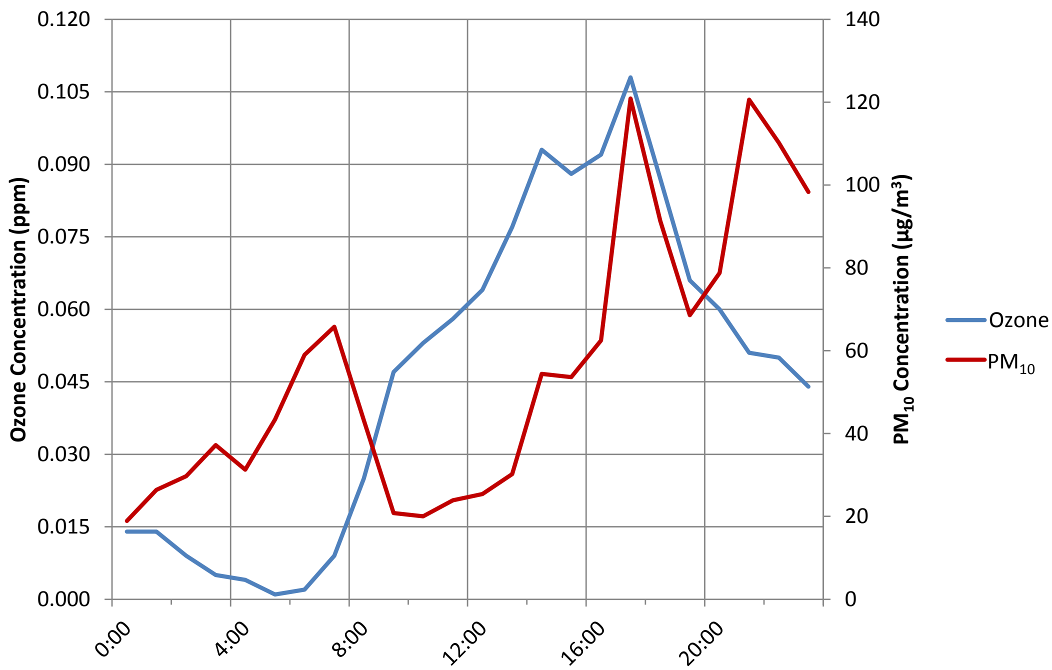


Figure 4-21. Hourly ozone and PM_{10} concentrations at KNI-Topeka on April 12, 2011. Ozone and PM_{10} concentrations both increased rapidly after 12:00 with the arrival of smoke.

April 13, 2011

The results below demonstrate that ozone and ozone precursors in smoke plumes from fires in the Flint Hills caused the 8-hour ozone concentrations above 0.075 ppm at Konza Prairie on April 13, 2011. Factors supporting this conclusion include

- Numerous fires burning in the Flint Hills region.
- Low-level winds and model trajectories indicating transport of smoke from fires to the impacted monitor.
- Reductions in visibility with rapid increases in ozone concentrations at the impacted monitor.
- No other unusual emission sources that would have caused the high ozone concentrations.

Existence of Fires

Fires on April 13, 2011, were again concentrated in the Flint Hills region, from northeastern Oklahoma northward to south of Topeka (**Figure 4-22**). KDHE estimated that 291,296 acres burned on April 13; this is the second highest daily burn acreage estimate in April 2011.

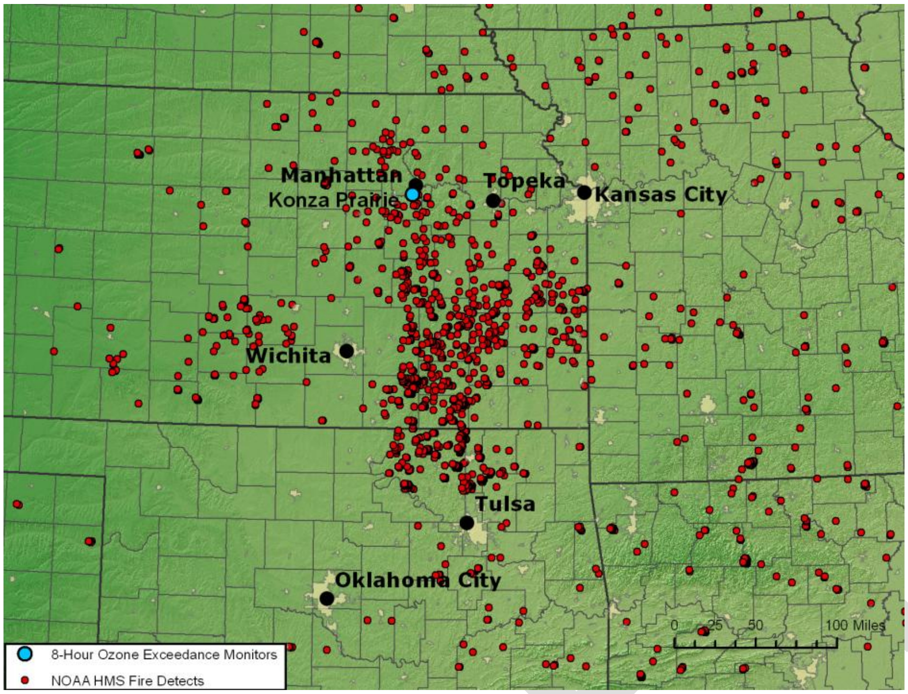


Figure 4-22. Fire locations on April 13, 2011, from NOAA-HMS. Numerous fires were detected in the Flint Hills region south and southeast of the Konza Prairie monitor.

Meteorological Conditions and Smoke Transport

Meteorological conditions supported the transport of smoke from fires in the Flint Hills to the Konza Prairie monitor. The upper-level ridge of high pressure over the central United States on April 12 shifted eastward and weakened slightly by April 13 (**Figure 4-23**). At the surface, a broad high pressure system encompassed the Gulf Coast states northward to the Great Lakes (**Figure 4-24)**. A frontal system was located across western Kansas in the morning; the front shifted slowly eastward through the day. Between the cold front and high pressure system, eastern Kansas had light to moderate south-southeasterly surface flow. Visible satellite imagery indicated a persistent area of mid- and high-level clouds throughout the day over the Konza Prairie monitor; persistent cloud cover is not typically associated with local ozone production. Smoke was evident over southeastern Kansas, where skies were otherwise clear; smoke was also evident across neighboring states (**Figure 4-25**).

Atmospheric stability conditions on April 13 indicated that smoke emitted at the surface was likely confined near the ground. The 06:00 KTOP sounding showed a temperature inversion from the surface to 300 m AGL with several weaker subsidence inversions aloft (**Figure 4-26**). The 18:00 KTOP sounding showed a stable layer between about 1700 and 2700 m AGL, indicating that smoke emitted at the surface was likely below 1700 m throughout the afternoon (**Figure 4-27**).

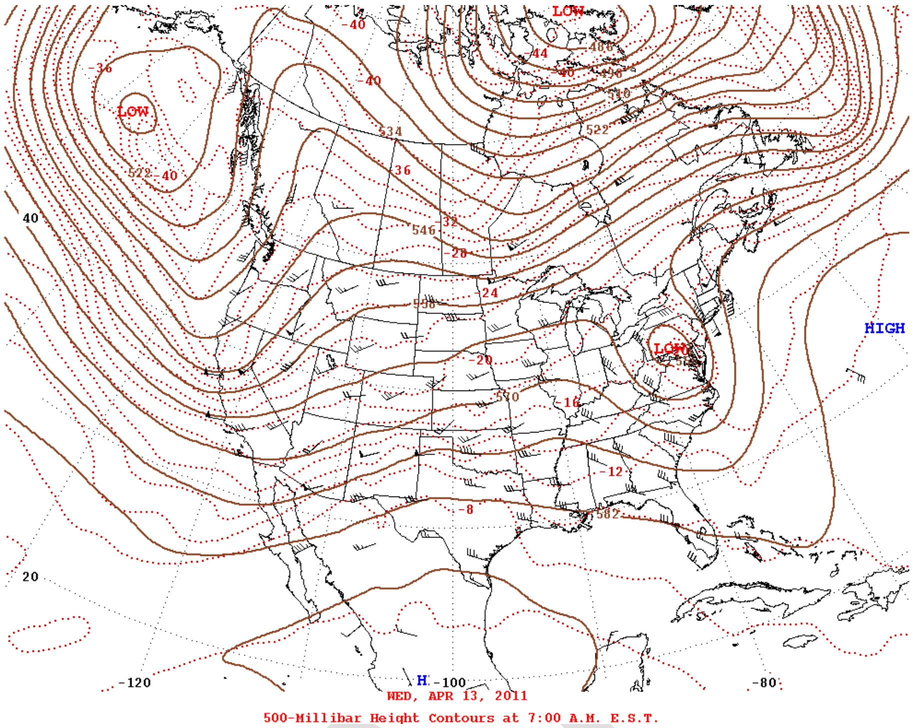


Figure 4-23. 500 mb heights for 06:00 on April 13, 2011, showing a ridge of high pressure east of Kansas. Source: NWS.

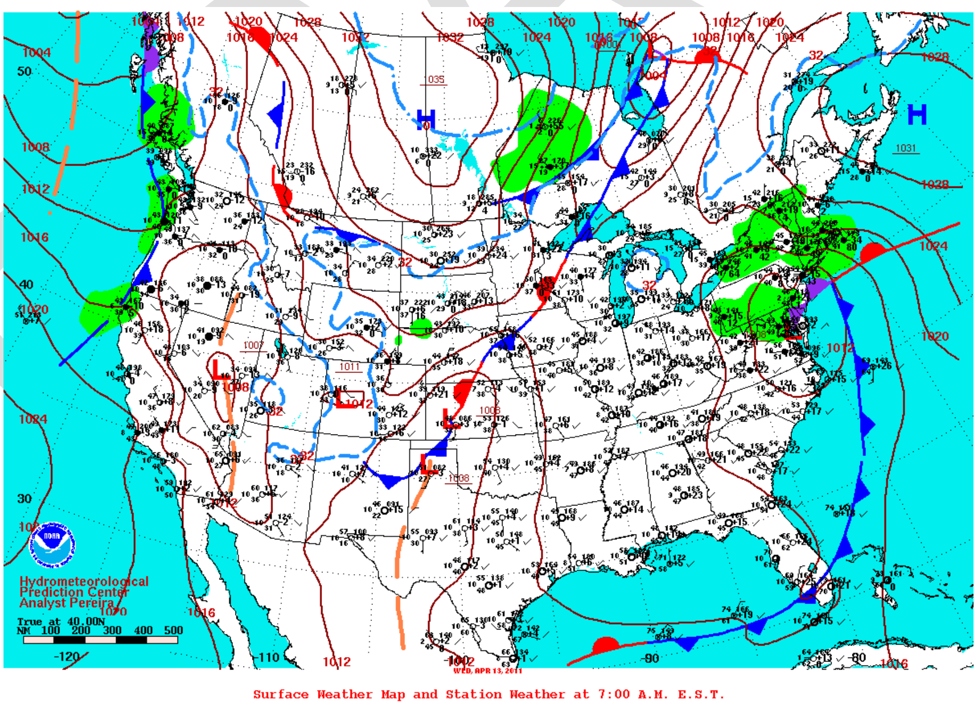


Figure 4-24. Surface weather map for 06:00 on April 13, 2011, showing a high pressure ridge over the Mississippi Valley that caused south-southeasterly winds across eastern Kansas. Source: NWS.

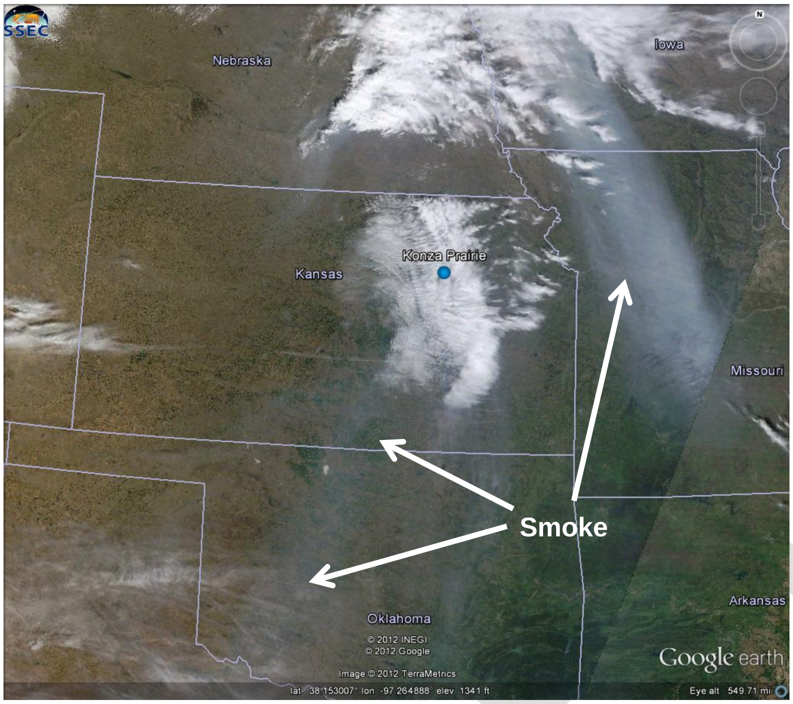


Figure 4-25. MODIS-TERRA visible satellite image from about 12:00 on April 13, 2011. Clouds (white) were present over Konza Prairie for much of the day, which is atypical of days with high ozone levels. Widespread smoke (gray) is visible over cloud-free regions of Kansas and neighboring states. Source: SSEC.

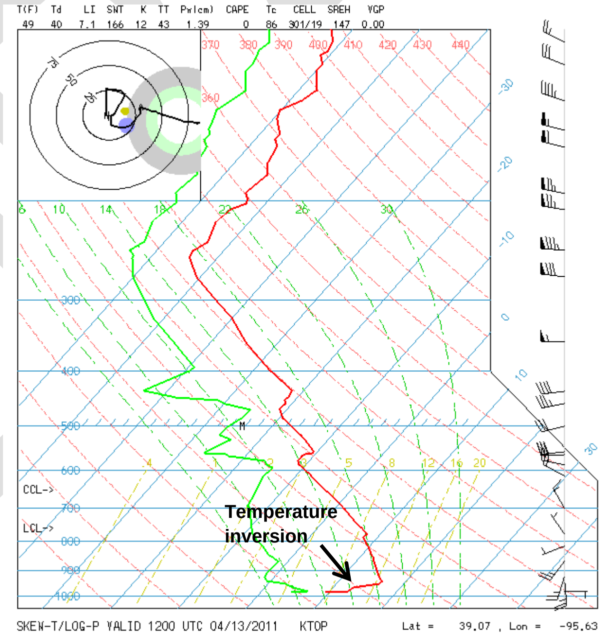


Figure 4-26. Radiosonde from KTOP at 06:00 on April 13, 2011. A temperature inversion at 300 m AGL indicated limited vertical mixing during the morning hours. Source: NWS.

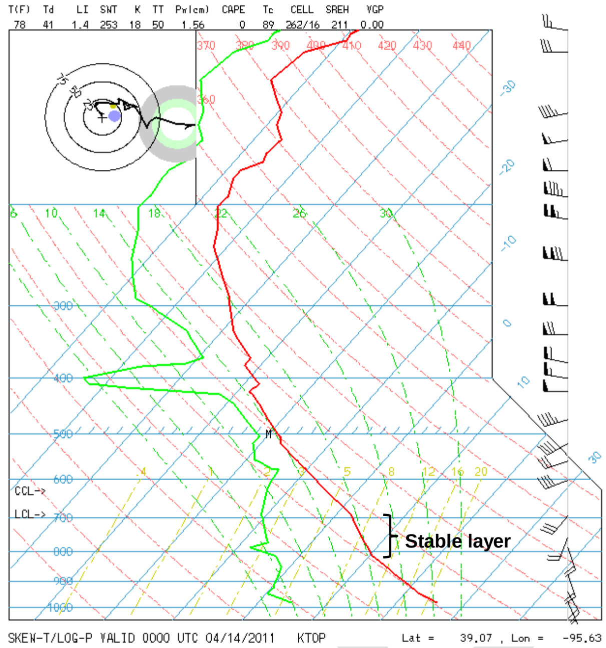


Figure 4-27. Radiosonde from KTOP at 18:00 on April 13, 2011. A stable layer between 1700 and 2700 m AGL likely prevented smoke emitted at the surface from mixing high into the atmosphere. Source: NWS.

24-hour backward trajectories ending at 10:00 on April 13 at Konza Prairie originated over southeastern Kansas and passed through the region of numerous April 12 fires in the Flint Hills (**Figure 4-28**). Trajectories ending at Konza Prairie in the afternoon continued to pass through fires and smoke in the Flint Hills (**Figure 4-29**); this is reflective of persistent south-southeasterly flow throughout the day across eastern Kansas (**Figure 4-30**). Because of the widespread smoke across the region, ozone formation was likely enhanced at monitors other than Konza Prairie. However, trajectories ending in Konza Prairie passed through the region of the most numerous fires in the Flint Hills, whereas similar trajectories ending in Wichita, Topeka, or Kansas City would have passed through fewer fires. Thus, the smoke impacts were likely most concentrated at Konza Prairie.

Air Quality Conditions

$PM_{2.5}$ and PM_{10} observations were not available at Konza Prairie. However, visibility observations at KMHK (five miles from Konza Prairie) showed haze and reduced visibility for much of the day, likely due to persistent smoke transport by south-southeasterly winds from fires in the Flint Hills (**Figure 4-31**). Ozone concentrations increased most rapidly at Konza Prairie between 06:00 and 09:00 and again between 12:00 and 14:00 before peaking at 15:00. In comparison, KICT and KFOE reported no visibility obstructions during the afternoon, and air quality monitors near those airports showed lower ozone concentrations, supporting the conclusion that smoke on April 13 affected Konza Prairie most strongly compared to other Kansas air quality monitors.

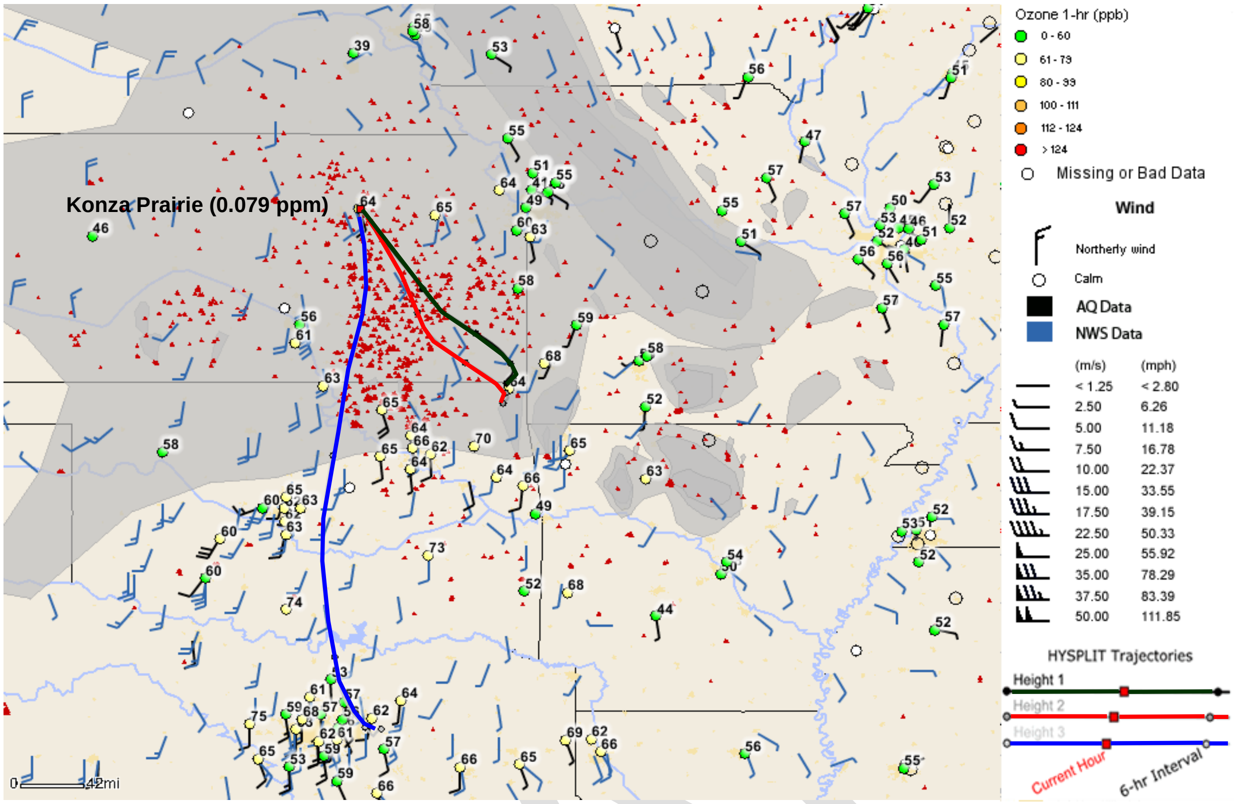


Figure 4-28. 24-hour backward HYSPLIT trajectories ending at 10:00 on April 13, 2011. Southeasterly winds over the 24-hour period transported smoke to the Konza Prairie monitor. Plot created in AIRNow-Tech.

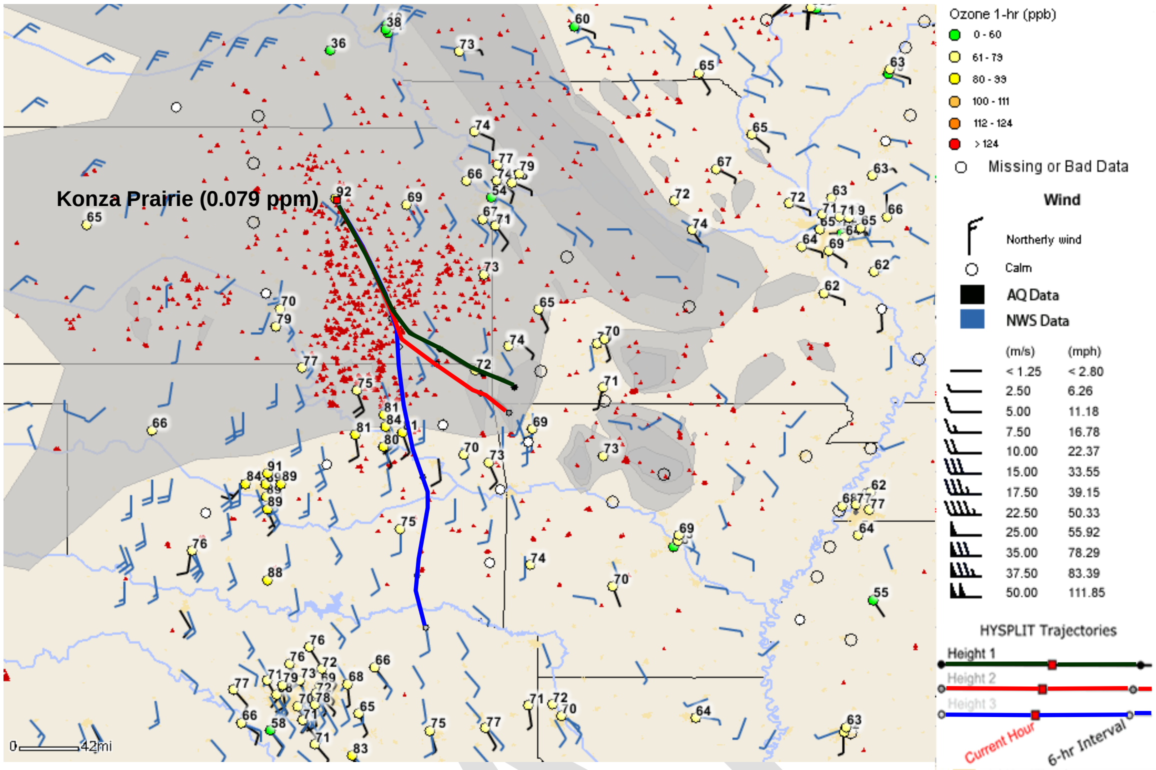


Figure 4-29. 24-hour backward HYSPLIT trajectories ending at 16:00 on April 13, 2011. Southeasterly winds passed over areas of numerous fires and transported smoke to the Konza Prairie monitor throughout the day. Plot created in AIRNow-Tech.

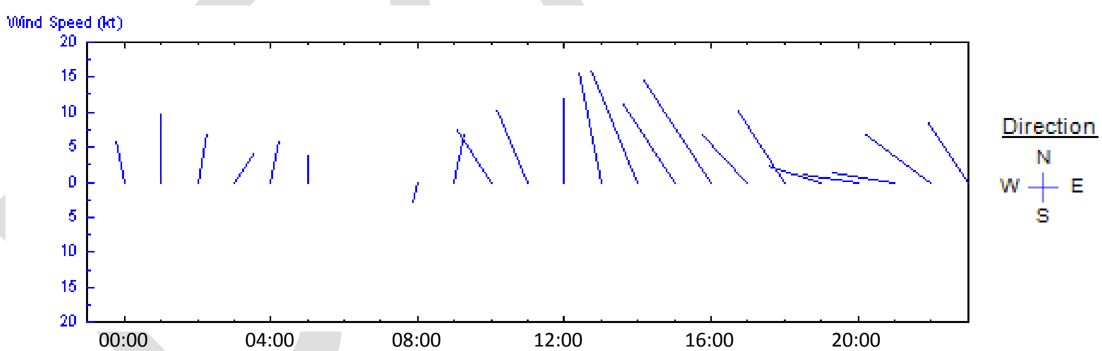


Figure 4-30. Hourly wind speed and direction at KMHK on April 13, 2011. Persistent south to southeasterly winds transported smoke to the Konza Prairie monitor. Lines point to direction in which wind is going.

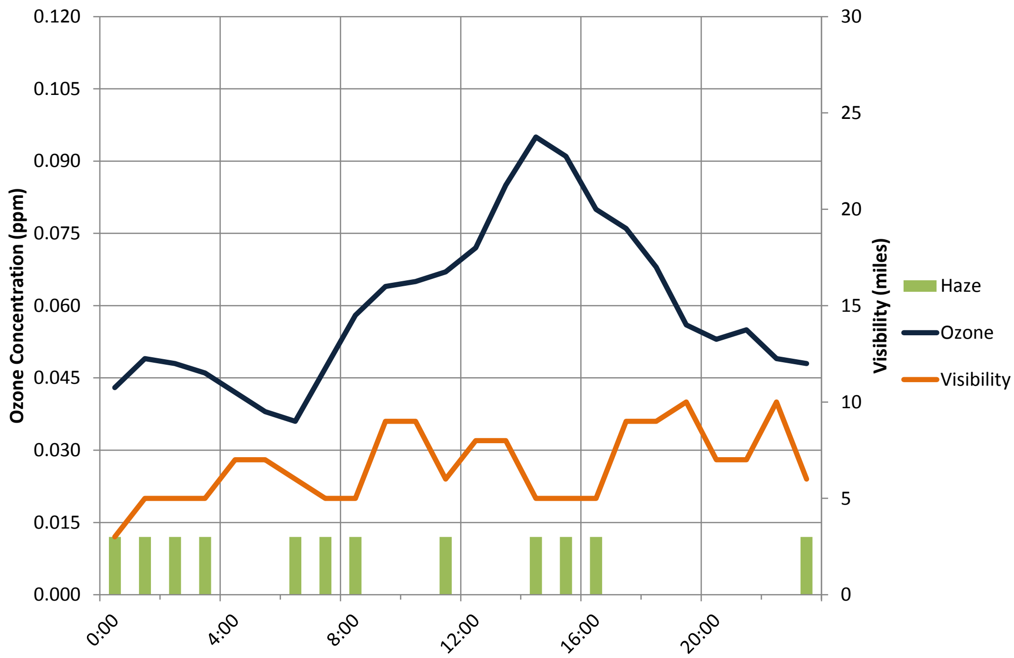


Figure 4-31. Hourly ozone concentrations at Konza Prairie and visibility at KMHK on April 13, 2011. Ozone concentrations increased rapidly between 06:00 and 09:00 and between 12:00 and 14:00, coincident with reductions in visibility and reports of haze, indicating the arrival of smoke from fires.

April 29, 2011

The results below demonstrate that ozone and ozone precursors in smoke plumes from fires in Texas and Mexico caused the 8-hour ozone concentrations above 0.075 ppm at the Peck and Sedgwick monitors on April 29, 2011. Factors supporting this conclusion include

- Numerous large fires burning in northern Texas.
- Low-level winds and model trajectories indicating transport of smoke from fires to the impacted monitors.
- No other unusual emission sources that would have caused the high ozone concentrations.

Existence of Fires

On April 29, 2011, numerous fires were burning in Texas and northeastern Mexico (**Figure 4-32**). Many of the Texas and Mexico fires had been burning since April 25.

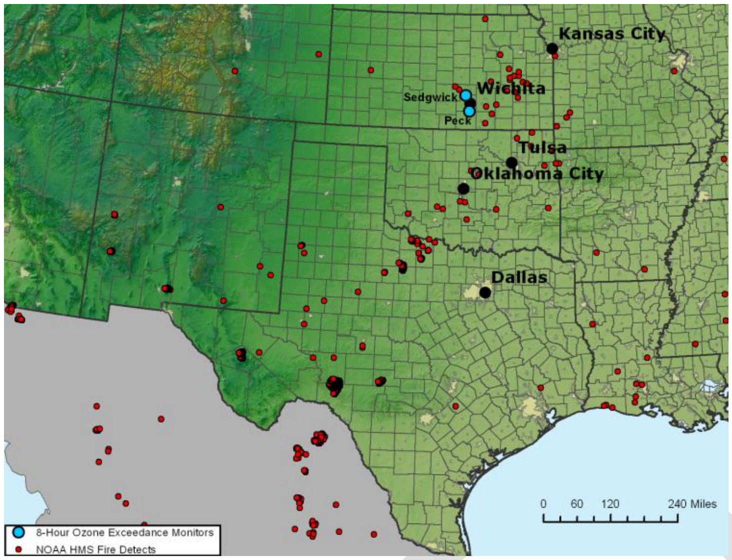


Figure 4-32. Fire locations on April 29, 2011, from NOAA-HMS. Several fires were detected in north-central and west Texas.

Meteorological Conditions and Smoke Transport

Meteorological conditions supported the transport of smoke from the fires in northern Texas to the Wichita-area monitors. Early on April 29, an upper-level ridge of high pressure was located over the central United States. Upper-level ridges are normally associated with increased atmospheric stability and reduced vertical mixing (**Figure 4-33**). At the surface, high pressure was located over the Gulf Coast region and a low-pressure system was organizing over the Rockies. Wichita was in a region of moderate southerly winds (**Figure 4-34**). Visible satellite imagery indicated mostly clear skies over Wichita with an area of high cirrus clouds passing over the region between 14:00 and 16:00. MODIS satellite imagery indicated widespread haze and/or smoke across the southern Plains, including the Wichita area (**Figure 4-35**).

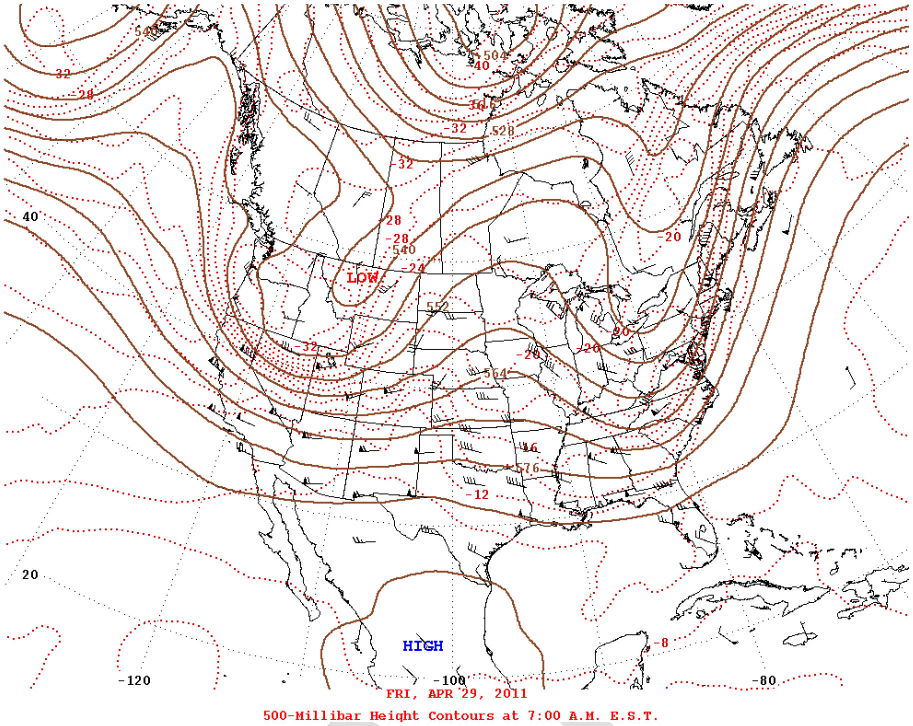


Figure 4-33. 500 mb heights for 06:00 on April 29, 2011, showing a strong ridge of high pressure over the central United States. Source: NWS.

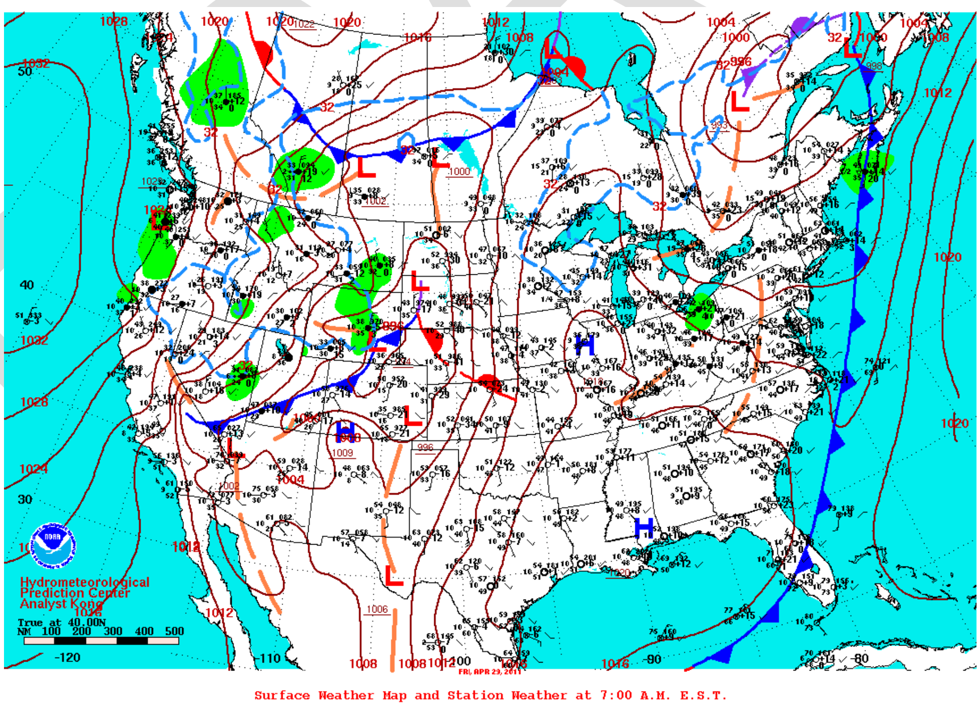


Figure 4-34. Surface weather map for 06:00 on April 29, 2011, showing high pressure over the Gulf Coast, with moderate southerly winds across Kansas. Source: NWS.

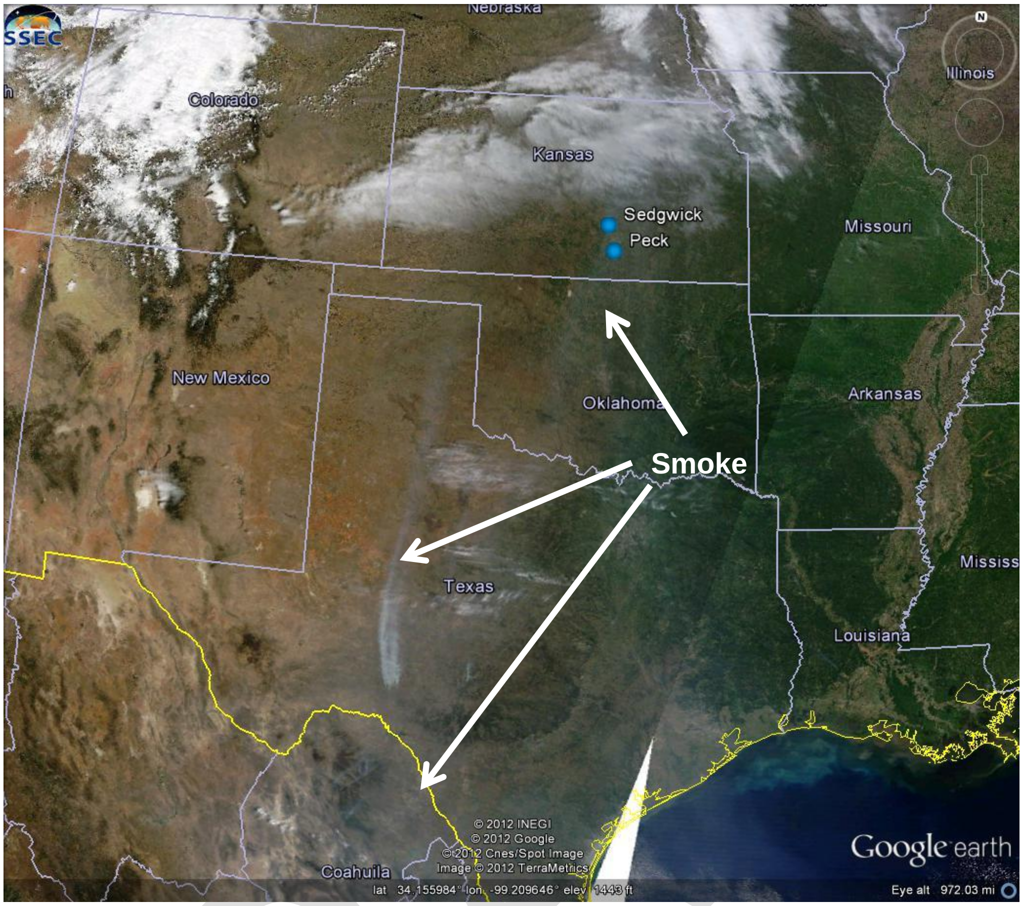


Figure 4-35. MODIS-TERRA visible satellite image from about 12:00 on April 29, 2011. Widespread smoke and haze is visible over northeast Mexico, west and north Texas, western Oklahoma, and south central Kansas. Source: SSEC.

Low-level atmospheric conditions over the Wichita area were conducive to long-range smoke transport while trapping incoming smoke near the surface. The KOUN sounding from 06:00 on April 29 showed a temperature inversion from the surface to nearly 300 m AGL (**Figure 4-36**). Winds were light at the surface but quickly increased to over 30 knots just above the inversion. The 18:00 KOUN sounding showed a well-mixed layer with strong southerly winds from the surface to a strong inversion near 1500 m AGL (**Figure 4-37**).

36-hour backward trajectories ending in the afternoon near Wichita originated in a large smoke plume over Texas and Oklahoma, indicating transport of smoke northward (**Figure 4-38**). Strong, persistent southerly winds observed in Wichita also indicate long-range transport of smoke from the fires in Texas (**Figure 4-39**). Wind gusts exceeded 40 knots in Wichita for several hours on April 29; wind speeds of this magnitude would normally disperse pollutants and are very atypical of high ozone levels. Compared to other Kansas air quality monitors, the monitors in the Wichita area were closer to the smoke sources and would have been impacted for a longer period of time by smoke. The trajectories also indicate potential transport from the Oklahoma City area; however, the BlueSky model results that captured emissions from Oklahoma City did not indicate that emissions from Oklahoma caused the high ozone concentrations in Kansas. This model result is consistent with strong dispersion of localized emissions due to the strong southerly winds.

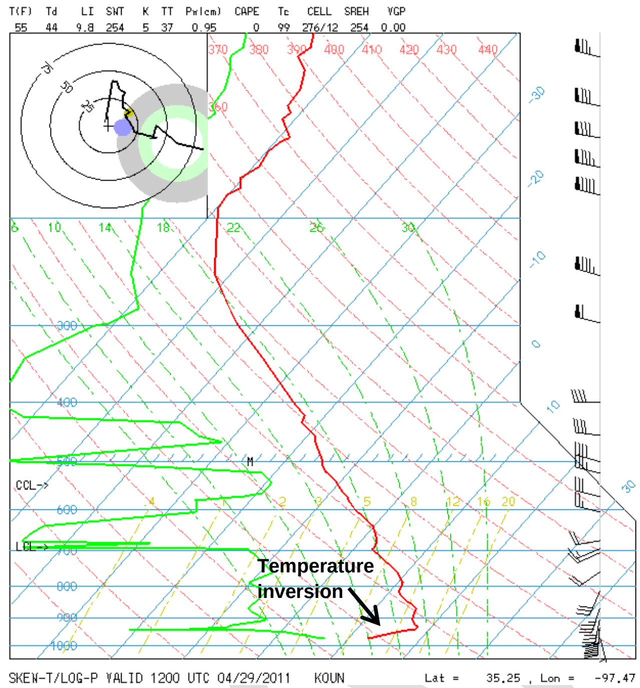


Figure 4-36. Radiosonde from KOUN at 06:00 on April 29, 2011, showing light winds and an inversion from the surface to 300 m AGL, indicating limited vertical mixing during the morning hours. Source: NWS.

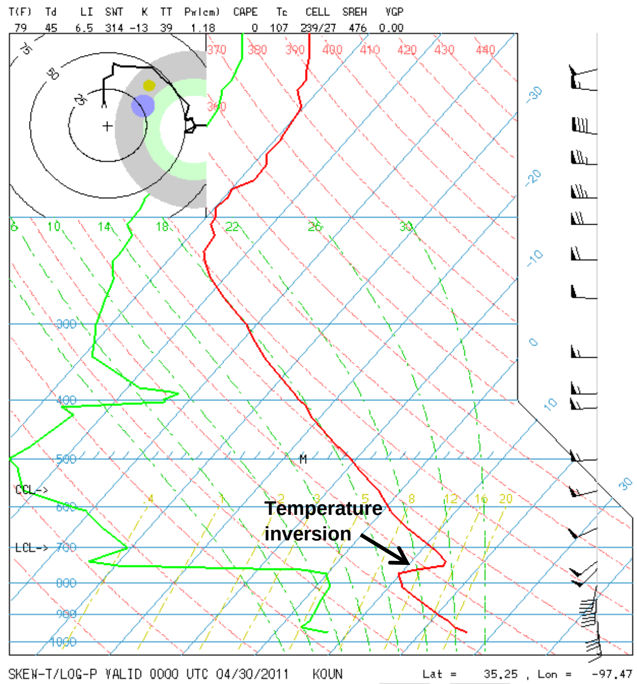


Figure 4-37. Radiosonde from KOUN at 18:00 on April 29, 2011. Moderate to strong winds through the mixed layer from the surface to 1500 m AGL transported smoke into the Wichita area. A stable layer and inversion above 1500 m likely confined incoming smoke beneath that level. Source: NWS.

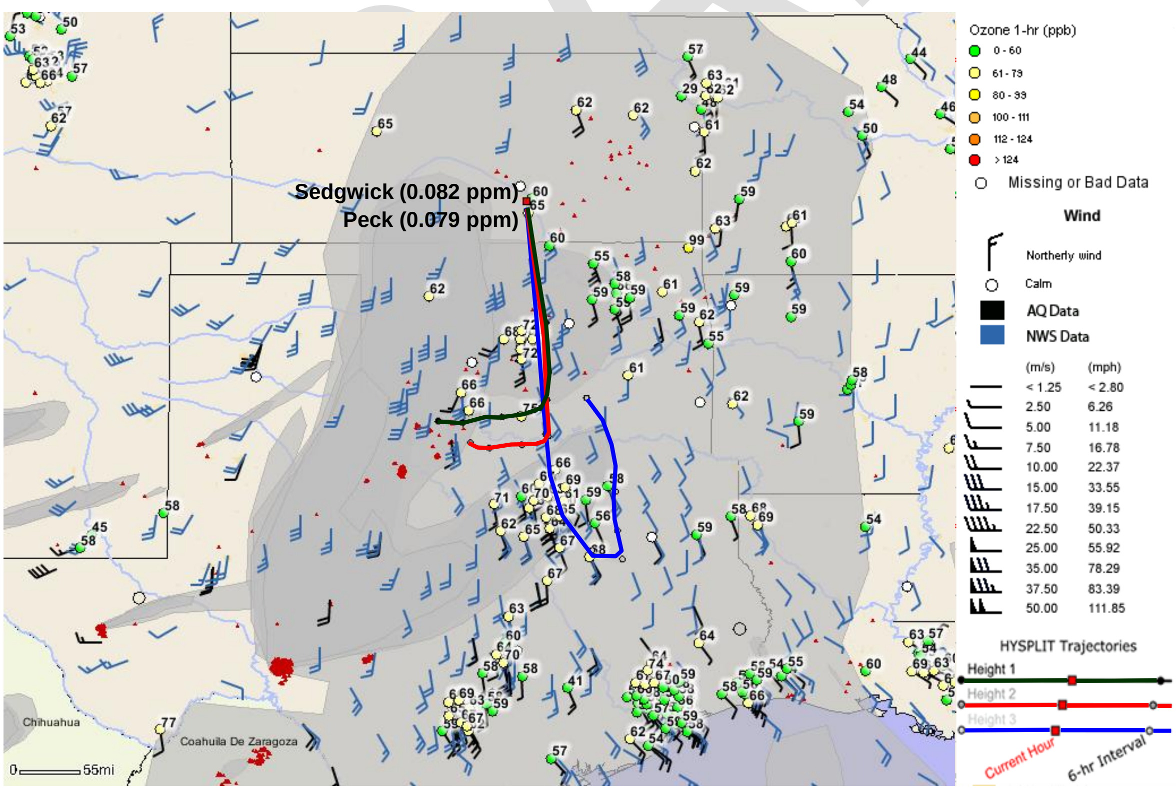


Figure 4-38. 36-hour backward HYSPLIT trajectories ending at 16:00 on April 29, 2011. Strong southerly winds continued to transport smoke into the Wichita area. Plot created in AIRNow-Tech.

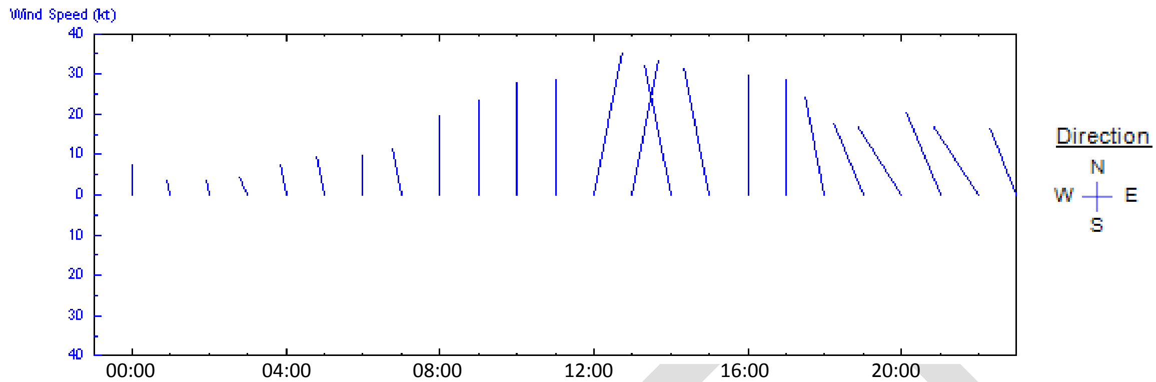


Figure 4-39. Hourly wind speed and direction at KICT on April 29, 2011. Southerly winds transported smoke into the Wichita area. Winds of this magnitude would normally disperse pollutants and are not typical of days with high ozone levels. Lines point to direction in which wind is going.

Air Quality Conditions

PM_{10} concentrations at Wichita area monitors were elevated, increasing steadily during the morning of April 29 and peaking at 13:00 (**Figure 4-40**). Visibility at KICT was not impaired on April 29 except for a brief reduction at 12:00, at which point PM_{10} concentrations were near their peak for the day. The strong winds on April 29 likely enhanced dispersion of the smoke as it moved northward into the Wichita area. This may explain why there was only a minimal effect on visibility compared to April 6, 12, and 13, when winds were lighter and the fires were much closer to the receptor monitors. Ozone concentrations at Wichita area monitors increased gradually through the day and peaked in the late afternoon (**Figure 4-41**), unlike the distinct, rapid increases and decreases in ozone concentrations noted on the other days with 8-hour ozone concentrations above 0.075 ppm.

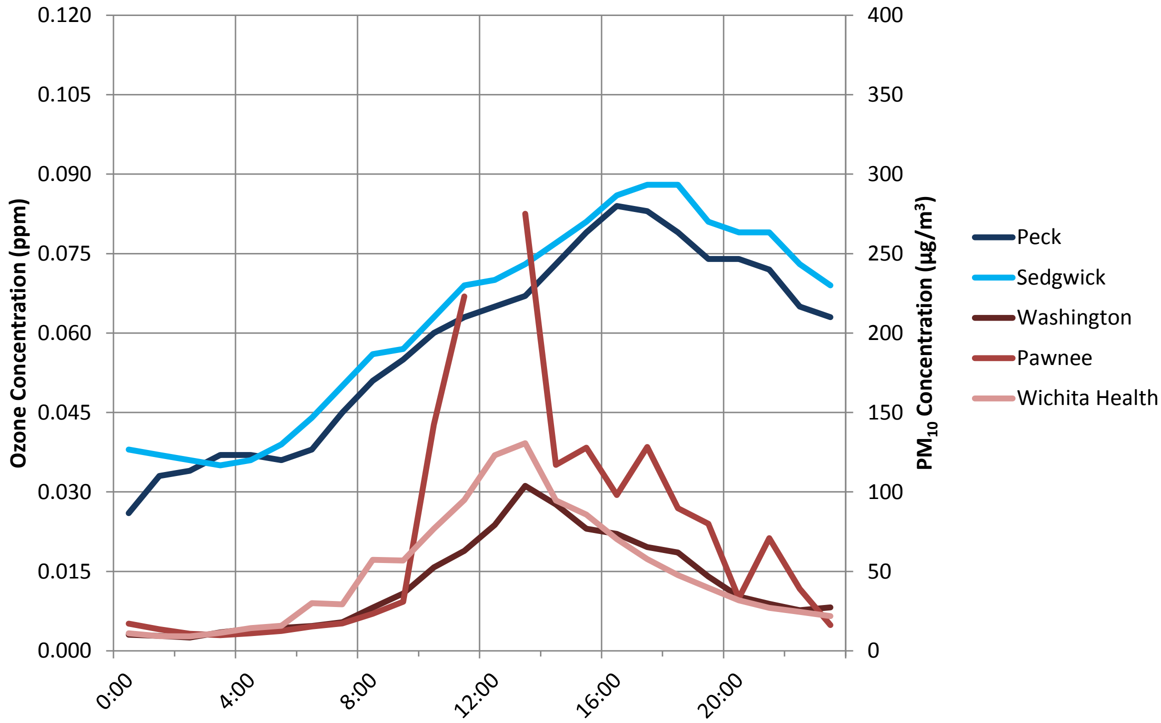


Figure 4-40. Hourly ozone (blue colors, top two lines) and PM_{10} (red colors, bottom three lines) concentrations at Wichita area monitors on April 29, 2011. Ozone concentrations increased steadily through the day, while PM_{10} concentrations increased significantly between 09:00 and 12:00. The strong winds on April 29 likely enhanced mixing and may have resulted in the smoother ozone diurnal profile compared to other days in April 2011 when 8-hour ozone concentrations were above 0.075 ppm. The PM_{10} concentration at 12:00 at Pawnee was missing. Monitor locations are shown in Figure 1-2.

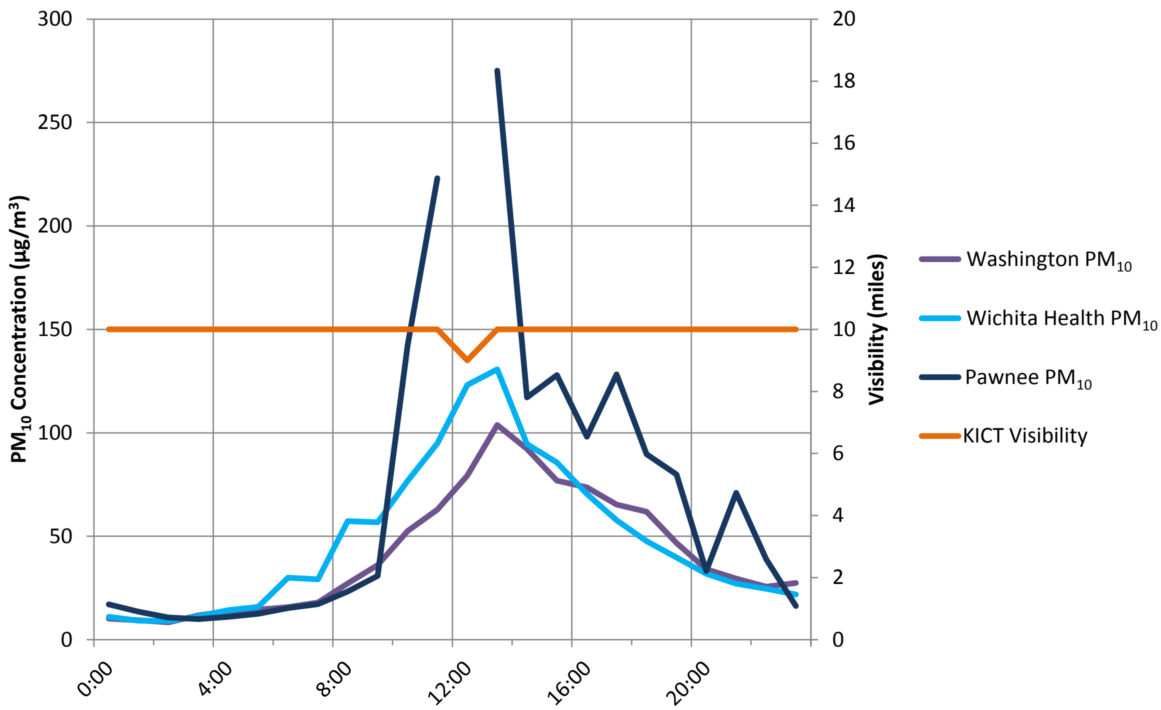


Figure 4-41. Hourly PM_{10} concentrations and visibility at Wichita area monitors on April 29, 2011. Visibility was marginally reduced at 12:00, coincident with high PM_{10} concentrations. The strong winds on April 29 likely enhanced mixing and resulted in better visibility compared to the other days in April 2011 when 8-hour ozone concentrations were above 0.075 ppm.

5. Historical Norm

5.1 Summary of Results

A weight of evidence of findings shows that ozone concentrations on April 6, 12, 13, and 29, 2011, were unusual and in excess of normal historical fluctuations. Key points include:

1. Maximum 8-hour and 1-hour ozone concentrations at the monitors where 8-hour ozone concentrations exceeded 0.075 ppm on April 6, 12, 13, and 29, 2011, were above the 95th percentile at each monitor for all April days in the 2006–2011 period.
2. In general, hourly ozone concentrations fluctuated more on the days when 8-hour ozone concentrations exceeded 0.075 ppm than on other days with elevated ozone levels but without smoke impacts.
3. Temperatures on April 6 and 12 were much cooler than on typical days with high ozone levels but without smoke impacts, and temperatures on April 13 and 29 were slightly cooler than on typical days with high ozone levels but without smoke impacts. The lower temperatures observed on these four days were unusual because high ozone levels are normally associated with warmer temperatures.
4. On April 6, 12, and 29, ozone concentrations were highest in the areas with greatest smoke impacts.
5. The 8-hour ozone concentrations above 0.075 ppm in April 2011 would not have occurred if the ozone concentrations on the hours likely impacted by smoke were replaced by the 95th percentile values.

5.2 Methods

Several techniques were employed to develop a weight of evidence demonstrating whether the measured ozone values on the April 2011 smoke-impact days, when 8-hour ozone concentrations exceeded 0.075 ppm, were in excess of normal historical fluctuations, including the following:

1. **Comparing observed ozone concentrations on the April 2011 smoke-impact days to historical observations.** The purpose of this analysis is to determine whether the observed ozone concentrations on the smoke-impact days were in excess of normal historical fluctuations; this is the primary method for assessing whether the 8-hour ozone concentrations on the smoke-impact days were unusual. For this assessment, historical daily cumulative distributions of daily 1-hour and 8-hour ozone were created by site for the April 2006–2011 period. Concentrations in excess of the 95th percentile are considered to be unusual[5].

[5] Excluding days on which concentrations caused by exceptional events exceed the 95th percentile threshold employs a general test of statistical significance and has the effect of ensuring that such concentrations would clearly fall beyond the range of normal expectations for air quality during a particular time of year. Source: "The Treatment of Data Influenced by Exceptional Events," 71 FR 12598

2. **Comparing diurnal ozone profiles on the April 2011 smoke-impact days to diurnal profiles on historical high ozone days.** Diurnal patterns in ozone concentrations on the April 2011 smoke-impact days were compared to diurnal patterns in ozone on typical days that showed high ozone concentrations but were not affected by smoke. Due to the very small number of days in which 8-hour ozone concentrations were above 0.075 ppm, "high ozone days" were defined as days with 8-hour ozone concentrations of at least 0.070 ppm. On the historical days with high ozone concentrations, smoke impacts were assessed at each monitor by visible satellite imagery, fire and smoke location data, and trajectory analysis; days with potential smoke impacts were excluded from this analysis. To obtain a larger set of historical high ozone days without smoke impacts for this comparison, days in both April and May 2006-2011 were used in this analysis.
3. **Comparing temperatures on the April 2011 smoke-impact days to historical high ozone days.** High ozone concentrations normally occur on warm, cloud-free days. If high temperatures at the monitors where 8-hour ozone concentrations exceeded 0.075 ppm on the April 2011 smoke-impact days are lower than temperatures on typical days with high ozone concentrations (and without smoke impacts), the ozone concentrations on the April 2011 smoke-impact days may be considered unusual. These comparisons were made using METAR observations from stations representative of conditions at the impacted monitors.
4. **Evaluating the spatial pattern of ozone concentrations on the April 2011 smoke-impact days.** The purpose of this analysis was to determine whether ozone concentrations were high at all sites in the area (i.e., high regional concentrations) or only at isolated locations (i.e., localized impacts). High ozone concentrations at only the isolated monitors most impacted by smoke may be considered unusual. For this evaluation, 8-hour ozone concentrations and fire and smoke locations were examined at monitors across the central and southern Plains region on the four smoke-impact days in April 2011 using AIRNow-Tech Navigator and GIS.
5. **Assessing replacement of ozone data on the April 2011 smoke-impact days with historical data.** The smoke-affected measurements on the April 2011 smoke-impact days may be considered unusual if their replacement with the 95th percentiles of the historical data set results in ozone levels below the 8-hour standard. For this evaluation, 95th percentiles of ozone concentrations by hour and monitor were calculated and plotted against the diurnal ozone profiles on the April 2011 smoke-impact days. The ozone measurements likely impacted by smoke were replaced with the 95th percentile values, and new 8-hour ozone concentrations were calculated. Smoke impact was assessed using the methods described in Section 4.3.

5.3 Findings

5.3.1 Historical Cumulative Distributions

The 8-hour ozone concentrations in April 2011 were above normal historical levels. Table 5-1 shows that the 8-hour ozone concentrations were above the 95th percentile compared to the historical data set at each monitor. **Figures 5-1 through 5-6** show histograms of daily 8-hour ozone concentrations at the six impacted monitors for all April days with available data since 2006 and the corresponding 95th percentile values. The 8-hour ozone concentrations on April 6 at Peck and Mine Creek, on April 12 at KNI-Topeka, and on April 29 at Sedgwick were the highest of any day at those sites in April in the multi-year data set. The April 6, 2011, 8-hour concentration at Mine Creek was the only value above 0.075 ppm in the historical data set at that monitor.

Table 5-1. Percentiles of 8-hour ozone concentrations on April 2011 smoke-impact days relative to the historical data set in April and May.

Monitor	Date in 2011	8-hour Ozone Concentration (ppm)	Percentile	Data Set Available
Mine Creek	April 6	0.076	100th	2006-2011
Peck	April 6	0.082	100th	2006-2011
Wichita Health Dept.	April 6	0.079	99th	2006-2011
KNI-Topeka	April 12	0.084	100th	2007-2011
Konza Prairie	April 12	0.078	98th	2006-2011
Konza Prairie	April 13	0.079	99th	2006-2011
Peck	April 29	0.077	98th	2006-2011
Sedgwick	April 29	0.082	100th	2009-2011

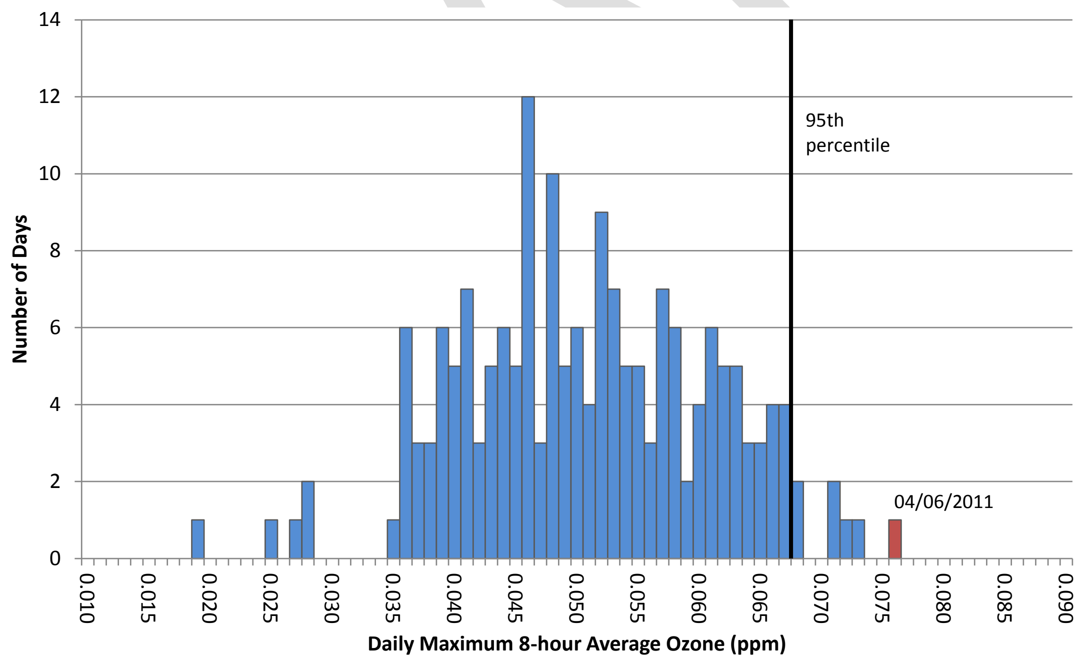


Figure 5-1. Daily maximum 8-hour average ozone concentrations at Mine Creek for April 2006-2011. The 8-hour ozone concentration on April 6, 2011 was in excess of the 95th percentile.

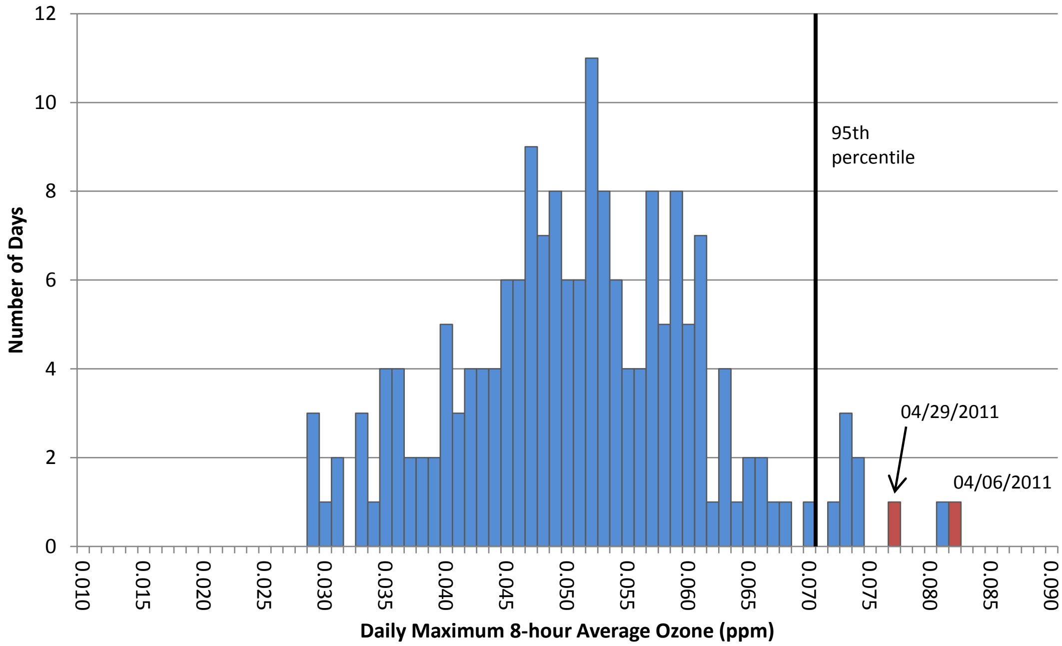


Figure 5-2. Daily maximum 8-hour average ozone concentrations at Peck for April 2006-2011. The 8-hour ozone concentrations on April 6 and 29, 2011, were in excess of the 95th percentile.

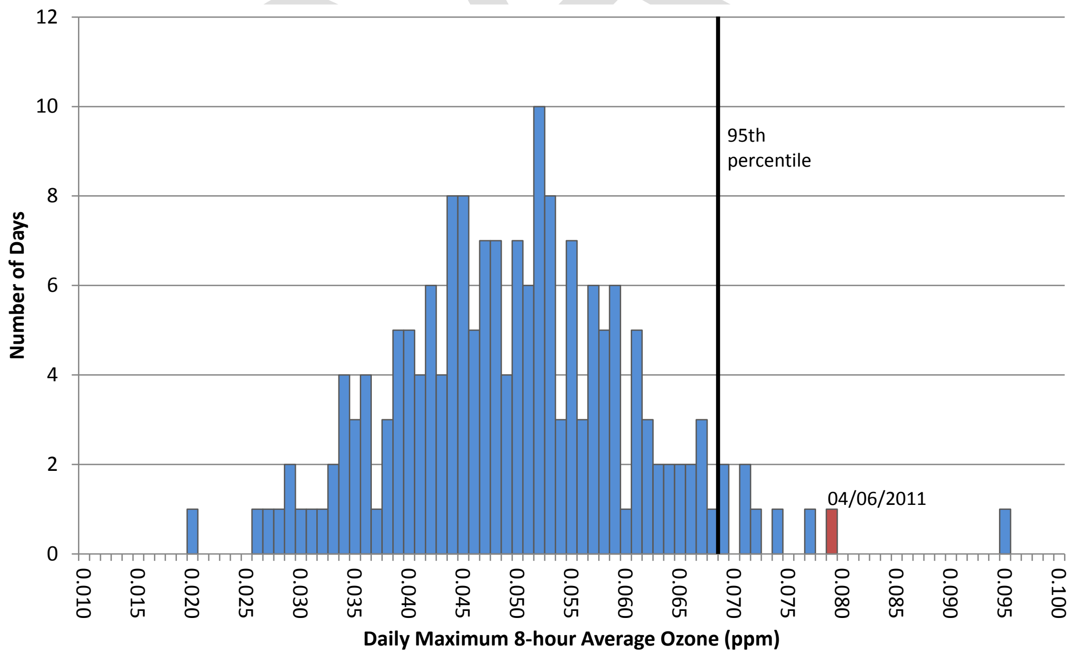


Figure 5-3. Daily maximum 8-hour average ozone concentrations at Wichita Health Dept. for April 2006-2011. The 8-hour ozone concentration on April 6, 2011, was in excess of the 95th percentile.

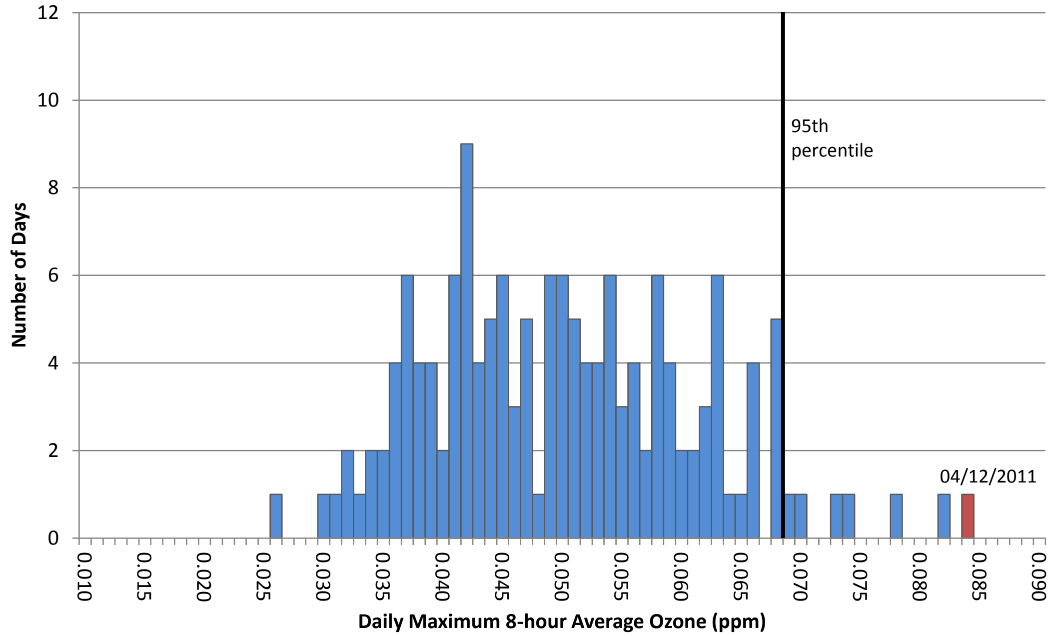


Figure 5-4. Daily maximum 8-hour average ozone concentrations at KNI-Topeka for April 2007-2011. The 8-hour ozone concentration on April 12, 2011, was in excess of the 95th percentile.

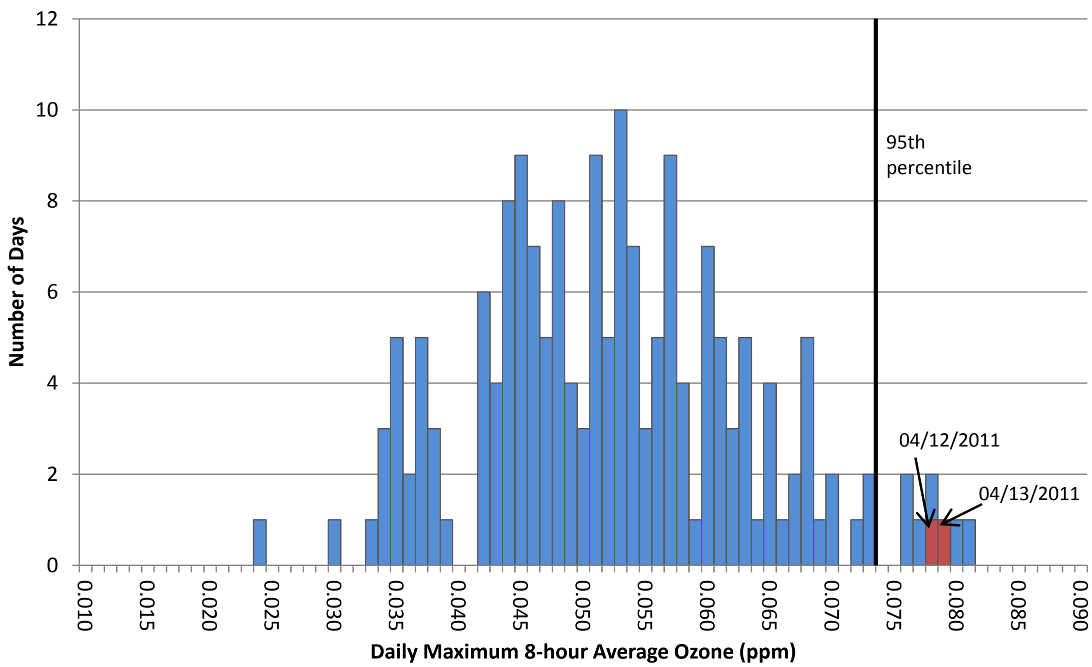


Figure 5-5. Daily maximum 8-hour average ozone concentrations at Konza Prairie for April 2006-2011. The 8-hour ozone concentrations on April 12 and 13, 2011, were in excess of the 95th percentile.

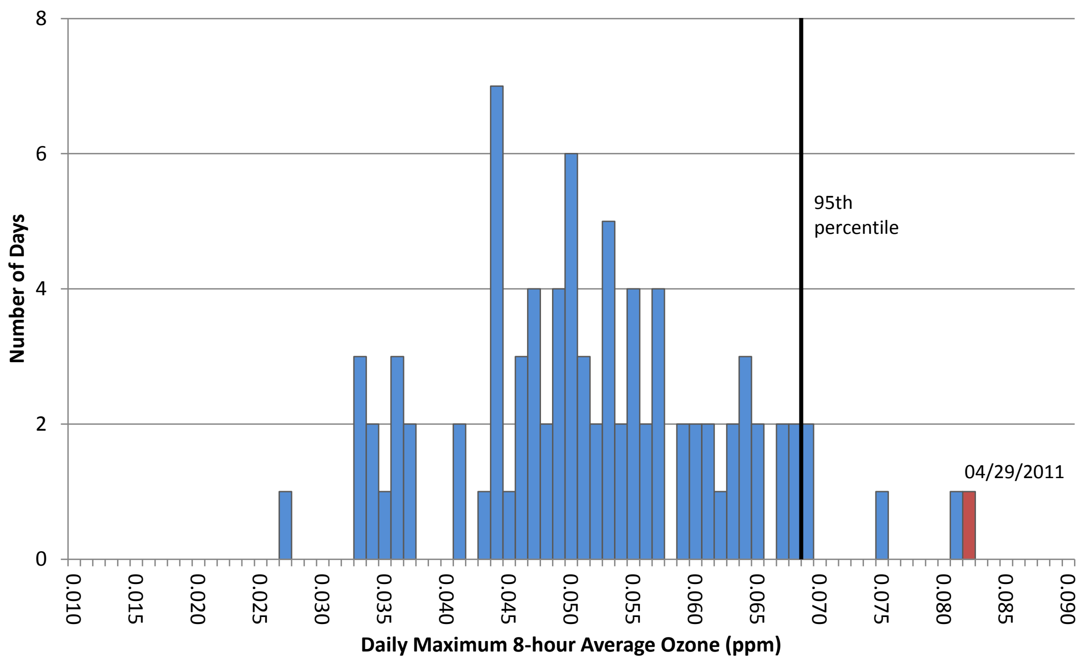


Figure 5-6. Daily maximum 8-hour average ozone concentrations at Sedgwick for April 2009-2011. The 8-hour ozone concentration on April 29, 2011, was in excess of the 95th percentile.

The daily maximum 1-hour ozone concentrations in April 2011 were above normal historical levels. Table 5-2 shows that the maximum 1-hour ozone concentrations at each monitor on the event days were above the 95th percentile, indicating that the observed ozone concentrations were very unusual. **Figures 5-7 through 5-12** show histograms similar to Figures 5-1 through 5-6, but for daily maximum 1-hour ozone concentrations. On April 6 at Mine Creek, April 12 at KNI-Topeka, and April 13 at Konza Prairie, the daily maximum 1-hour ozone concentrations reported were the highest hourly readings reported at those monitors on any April day in the historical data set, illustrating the infrequency of these events.

Table 5-2. Percentiles of 1-hour ozone concentrations on smoke-impact days in April 2011 relative to historical data set.

Monitor	Date in 2011	Max 1-hour Ozone Concentration (ppm)	Percentile	Data Set Available
Mine Creek	April 6	0.091	100th	2006-2011
Peck	April 6	0.109	99th	2006-2011
Wichita Health Dept.	April 6	0.102	99th	2006-2011
KNI-Topeka	April 12	0.108	100th	2007-2011
Konza Prairie	April 12	0.088	96th	2006-2011
Konza Prairie	April 13	0.095	100th	2006-2011
Peck	April 29	0.084	97th	2006-2011
Sedgwick	April 29	0.088	97th	2009-2011

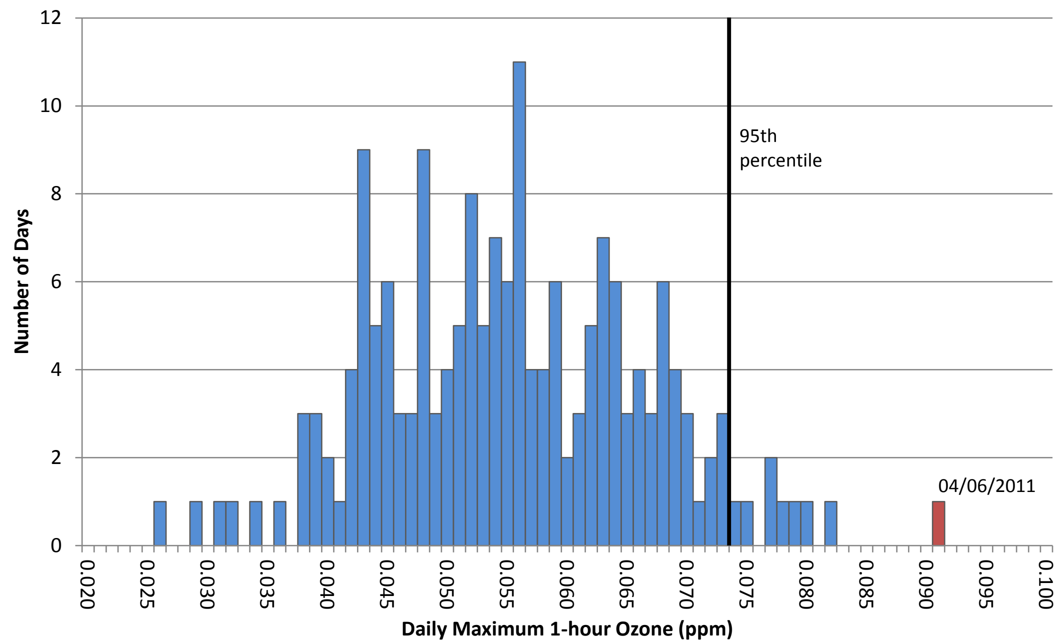


Figure 5-7. Daily maximum 1-hour ozone concentrations at Mine Creek for April 2006-2011. The maximum 1-hour ozone concentration on April 6, 2011, was in excess of the 95th percentile.

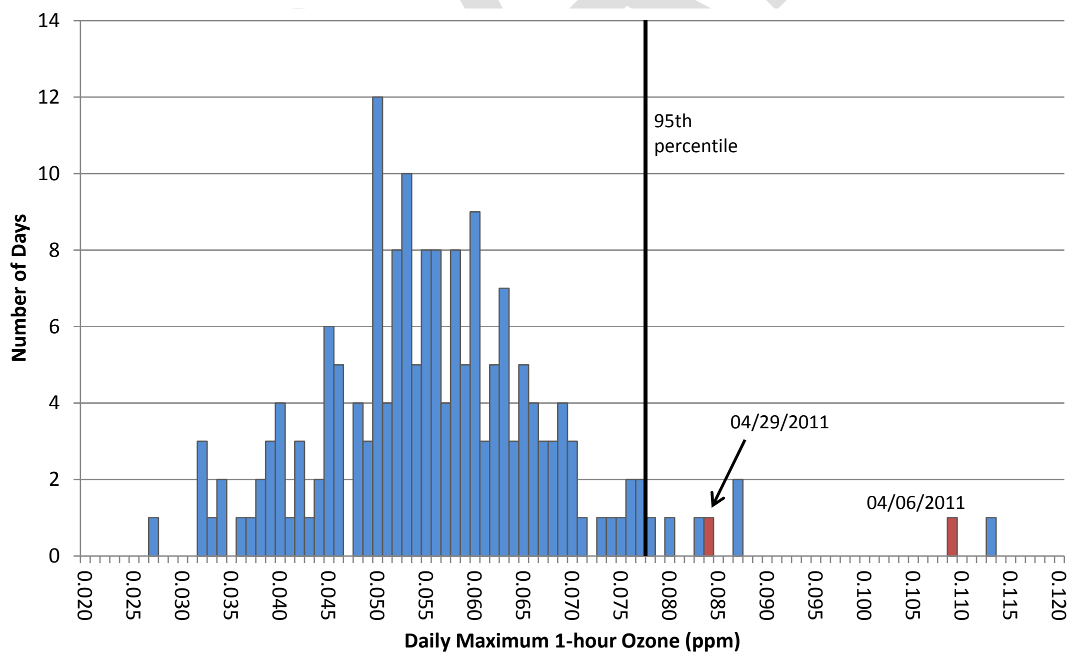


Figure 5-8. Daily maximum 1-hour ozone concentrations at Peck for April 2006-2011. The maximum 1-hour ozone concentrations on April 6 and 29, 2011, were in excess of the 95th percentile.

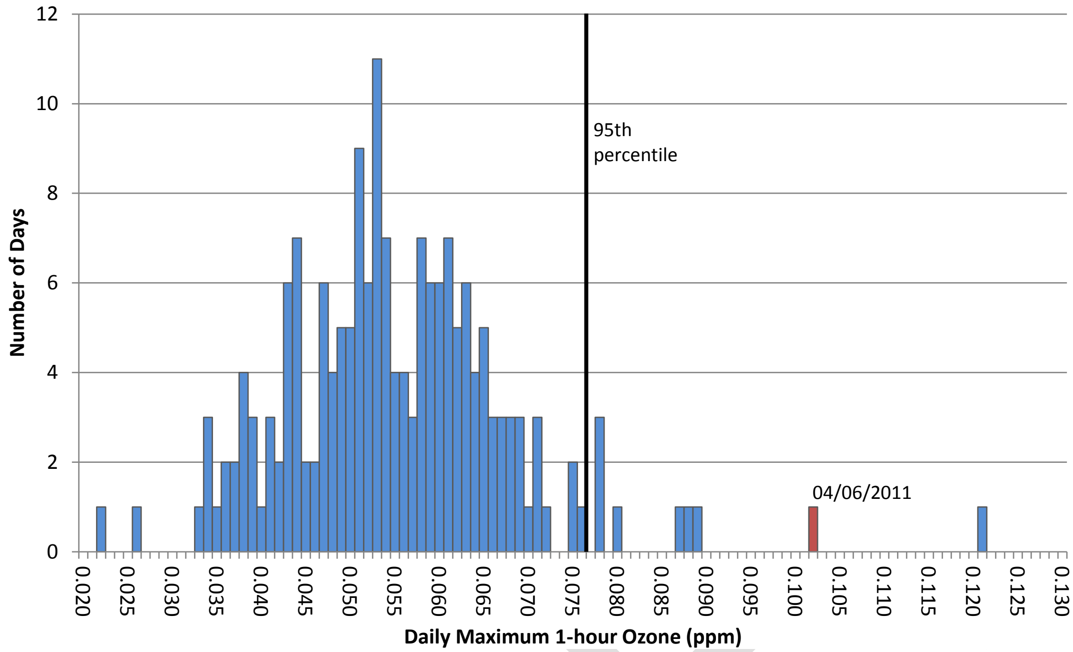


Figure 5-9. Daily maximum 1-hour ozone concentrations at Wichita Health Dept. for April 2006-2011. The maximum 1-hour ozone concentration on April 6, 2011, was in excess of the 95th percentile.

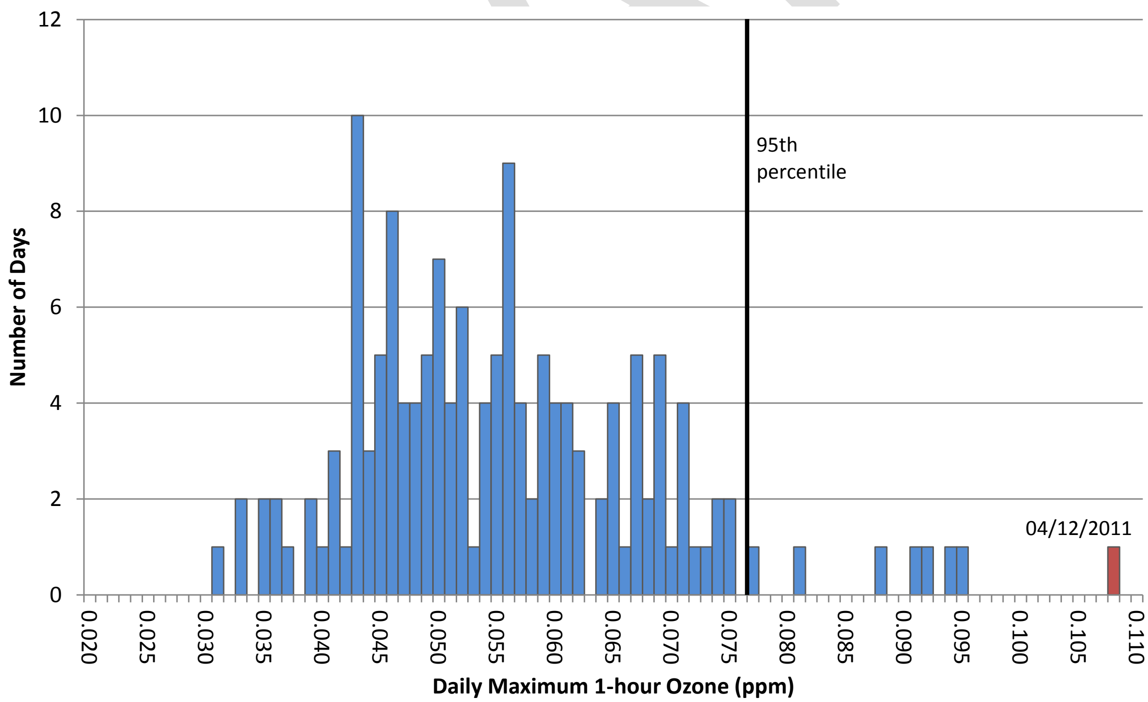


Figure 5-10. Daily maximum 1-hour ozone concentrations at KNI-Topeka for April 2007-2011. The maximum 1-hour ozone concentration on April 12, 2011, was in excess of the 95th percentile.

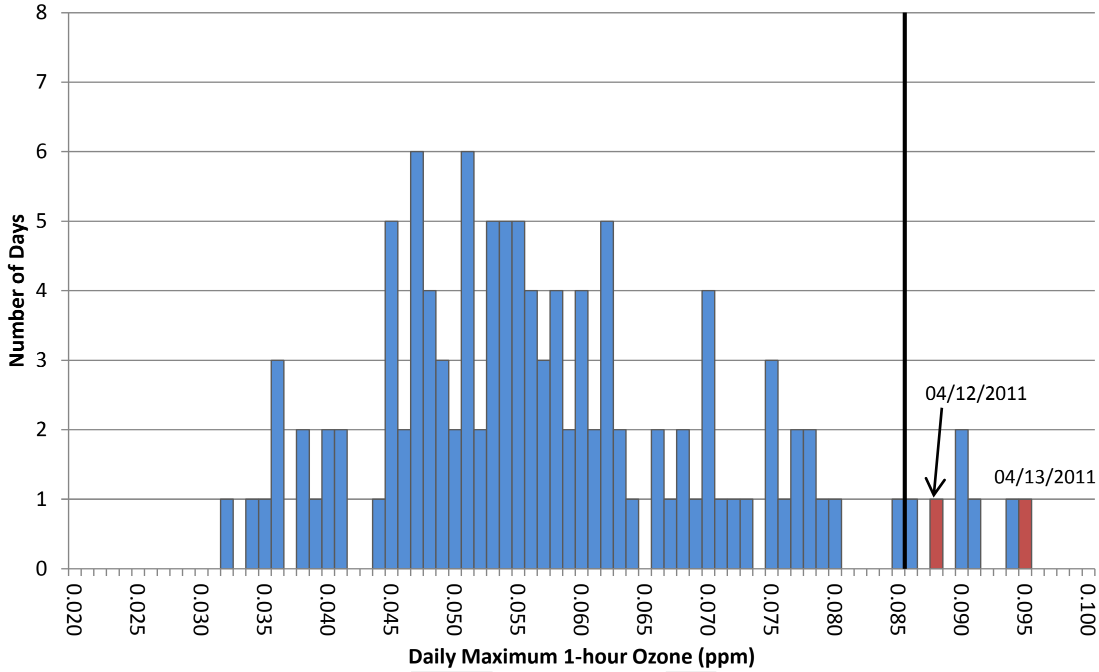


Figure 5-11. Daily maximum 1-hour ozone concentrations at Konza Prairie for April 2006-2011. The maximum 1-hour ozone concentrations on April 12 and 13, 2011, were in excess of the 95th percentile.

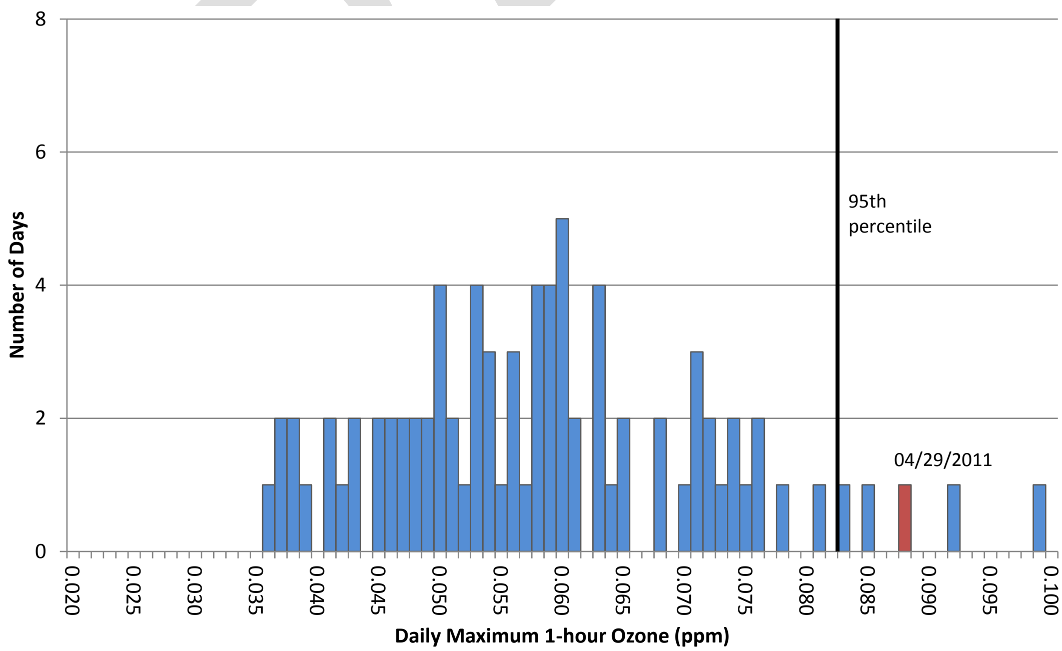


Figure 5-12. Daily maximum 1-hour ozone concentrations at Sedgwick for April 2009-2011. The maximum 1-hour ozone concentration on April 29, 2011, was in excess of the 95th percentile.

5.3.2 Diurnal Ozone Profiles

Diurnal ozone profiles at the smoke-impacted monitors on April 6, 12, and 13 were different from profiles at monitors that were not affected by smoke and suggest smoke impacts at specific hours. Figures 5-13 through 5-16 show time series of hourly ozone concentrations at all Kansas monitors on the four April 2011 event days. On April 6 (Figure 5-13), ozone concentrations spiked at the Wichita area monitors at 15:00, coincident with decreases in visibility and increases in PM_{10} concentrations. In contrast, the Kansas monitors without apparent smoke impacts did not show distinct spikes in ozone levels. Spikes in ozone concentrations were also evident on the afternoons of April 12 (Figure 5-14) and April 13 (Figure 5-15) at the monitors affected by smoke on those days.

Diurnal ozone profiles at the impacted monitors on April 29 (**Figure 5-16**) **were smoother than on the other smoke-impact days in April 2011.** Possible reasons for this observation include (1) mixing due to the very strong winds in the vicinity of the impacted monitors and (2) a smoke plume that may have been less well-defined spatially—since the smoke was transported from relatively distant fires in north Texas and Mexico—than the distinct smoke plumes from nearby fires in the Flint Hills on the other smoke-impact days.

Diurnal ozone profiles on the April 2011 smoke-impact days were different from diurnal ozone profiles on historical high-ozone, non-smoke-impact days, suggesting that the ozone observations on the April 2011 smoke-impact days were unusual. Figures 5-17 through 5-22 show comparisons at each monitor. In general, the historical days with high ozone concentrations exhibited smoother diurnal ozone profiles than the event days in April 2011, except for April 29 when strong winds likely enhanced mixing of the smoke plume.

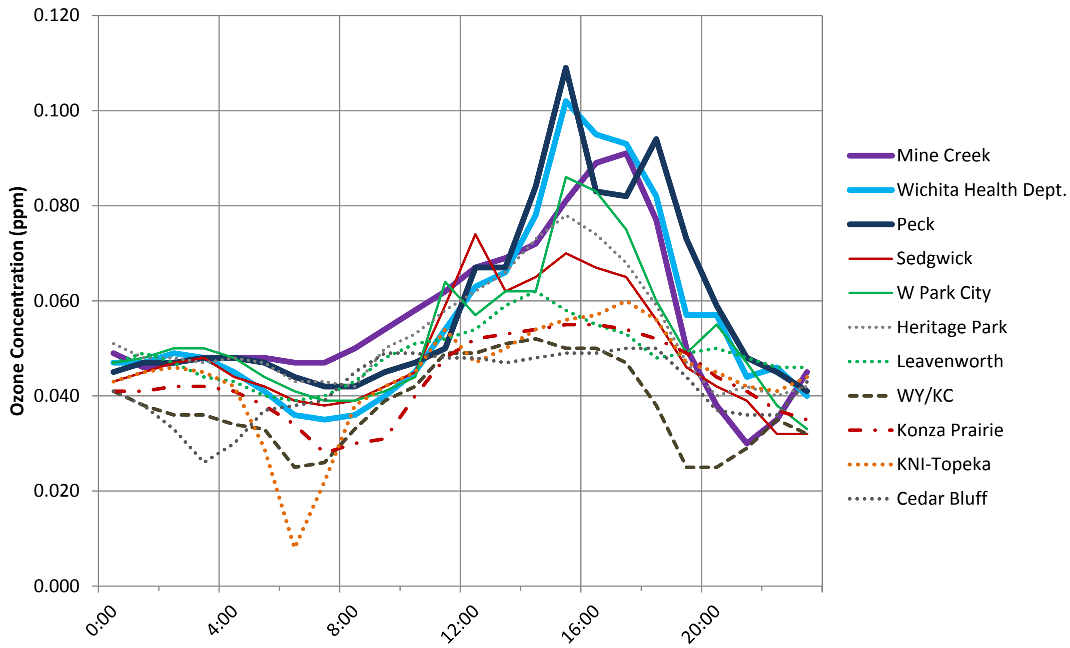


Figure 5-13. Hourly ozone concentrations at Kansas air quality monitors on April 6, 2011. Ozone concentrations at the impacted monitors (thick lines) spiked at distinct hours, likely due to smoke influence at the monitors. The monitors with little or no smoke impacts (thin or dashed lines) generally had smoother diurnal ozone profiles.

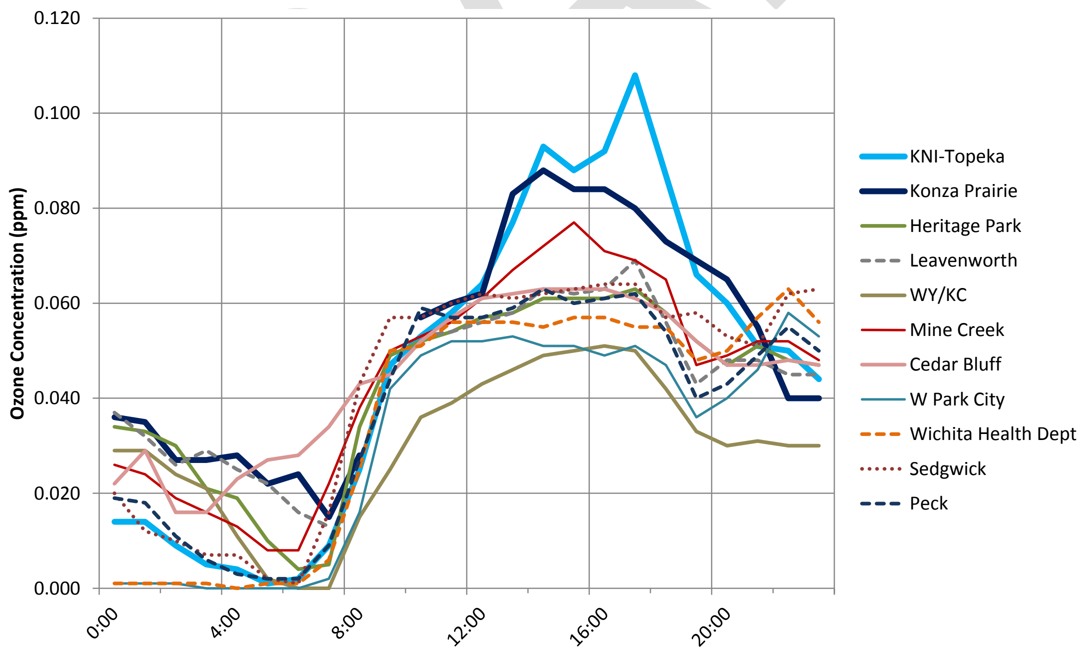


Figure 5-14. Hourly ozone concentrations at Kansas air quality monitors on April 12, 2011. Ozone concentrations at the impacted monitors (thick lines) spiked at distinct hours, likely due to smoke influence at the monitors. The monitors with little or no smoke impacts (thin or dashed lines) generally had smoother diurnal ozone profiles.

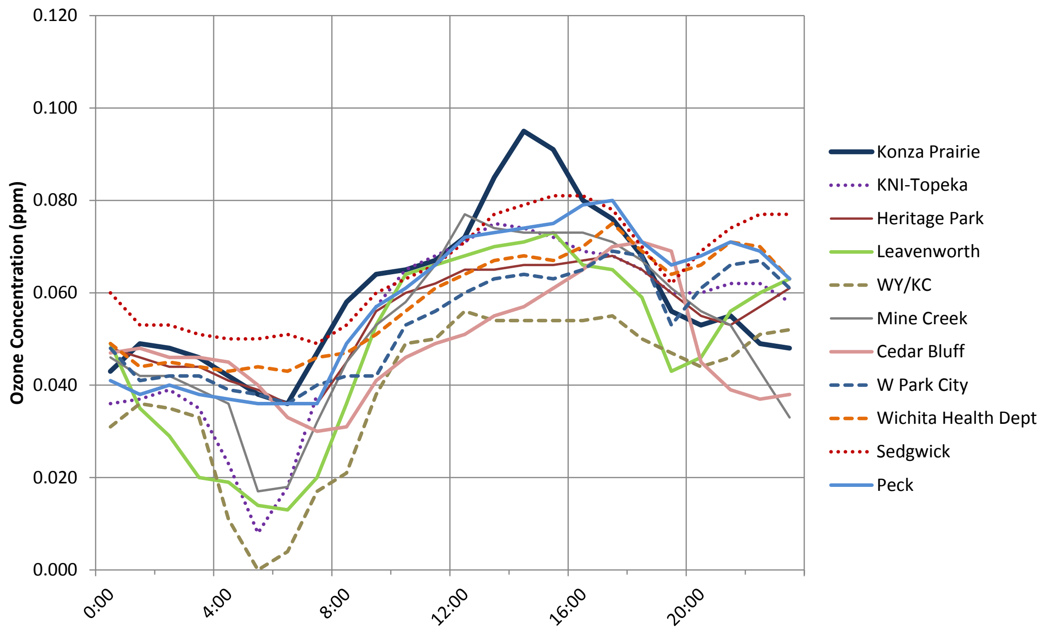


Figure 5-15. Hourly ozone concentrations at Kansas air quality monitors on April 13, 2011. Ozone concentrations at the impacted monitors (thick line) spiked at distinct hours, likely due to smoke influence at the monitors. The monitors with little or no smoke impacts (thin or dashed lines) generally had smoother diurnal ozone profiles.

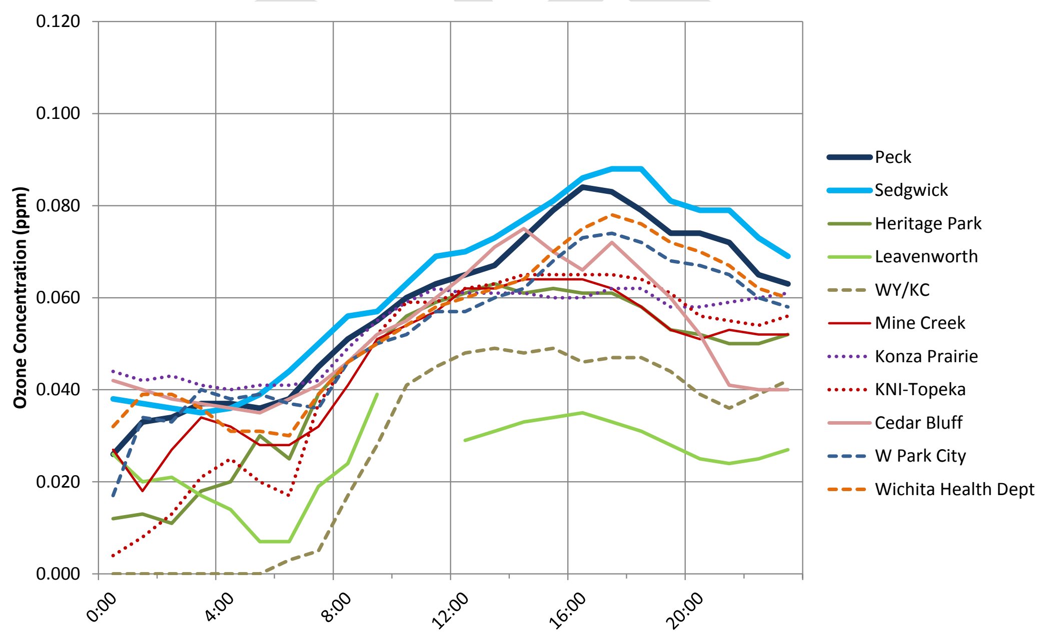


Figure 5-16. Hourly ozone concentrations at Kansas air quality monitors on April 29, 2011. In contrast to the April 6, 12, and 13, 2011, ozone concentrations at both smoke-impacted monitors (thicker lines) and monitors with little or no smoke impacts (thin or dashed lines) were relatively smooth, possibly due to enhanced mixing from strong southerly winds and plume spread associated with long-range transport.

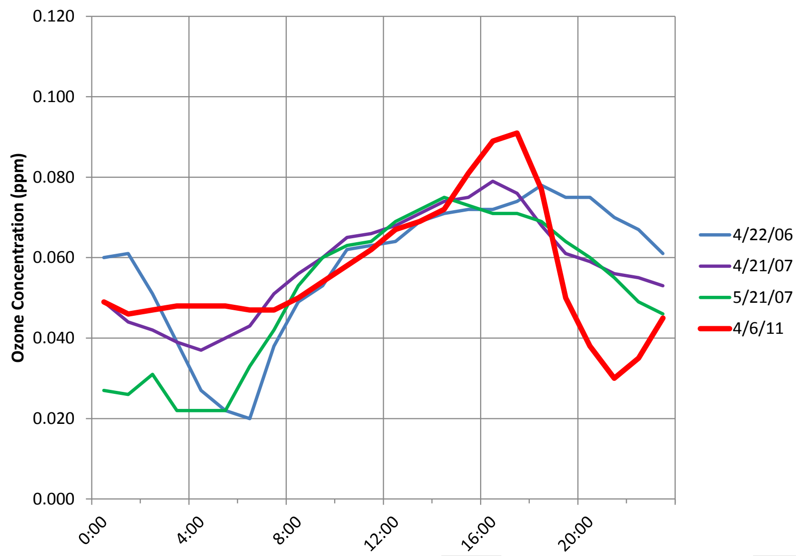


Figure 5-17. Ozone concentrations on April 6, 2011, and historical days with high ozone concentrations but without smoke impacts at Mine Creek. Ozone concentrations on April 6, 2011 (red line) spiked at distinct hours, likely due to the presence of smoke at the monitor. The historical days had smoother diurnal ozone profiles.

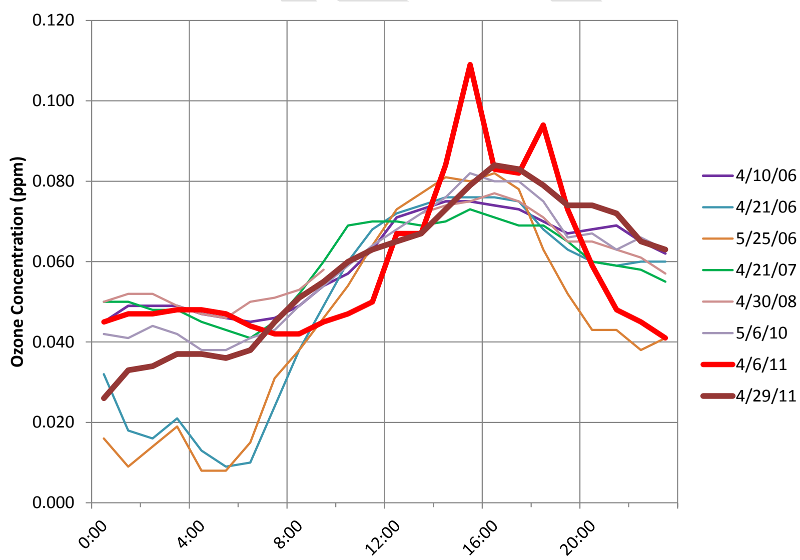


Figure 5-18. Ozone concentrations on April 6 and 29, 2011, and historical days with high ozone concentrations but without smoke impacts at Peck. Ozone concentrations on April 6, 2011 (thick red line) spiked at distinct hours, likely due to the presence of smoke at the monitor. The diurnal ozone profile on April 29, 2011 (thick brown line) was smoother, possibly due to mixing from strong winds and plume spread associated with long-range transport. The historical days with high ozone concentrations (thin lines) also had smoother diurnal ozone profiles.

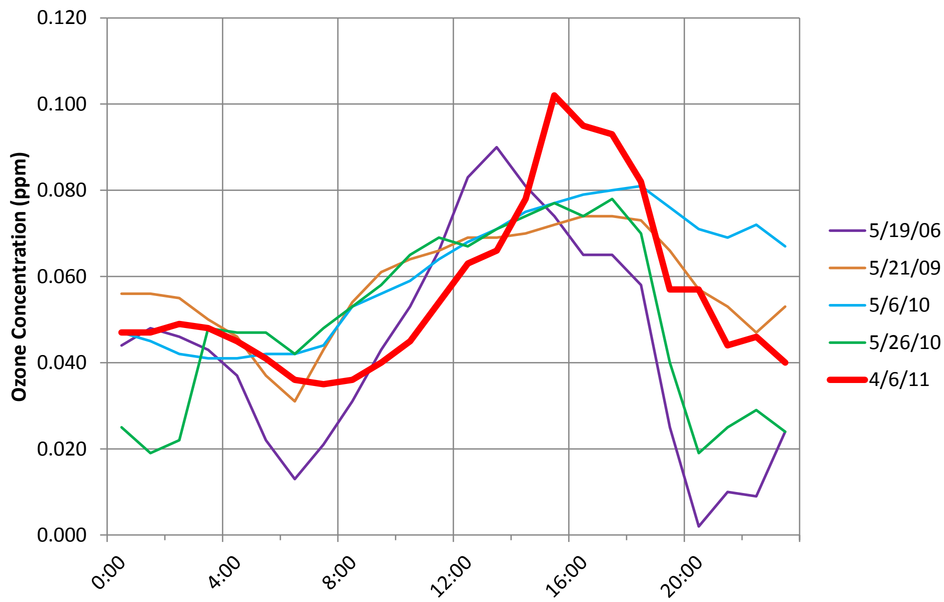


Figure 5-19. Ozone concentrations on April 6, 2011, and historical days with high ozone concentrations but without smoke impacts at Wichita Health Dept. Ozone concentrations on April 12, 2011 (thick red line) spiked at distinct hours, likely due to the presence of smoke at the monitor. All but one of the historical days with high ozone concentrations had smoother diurnal ozone profiles.

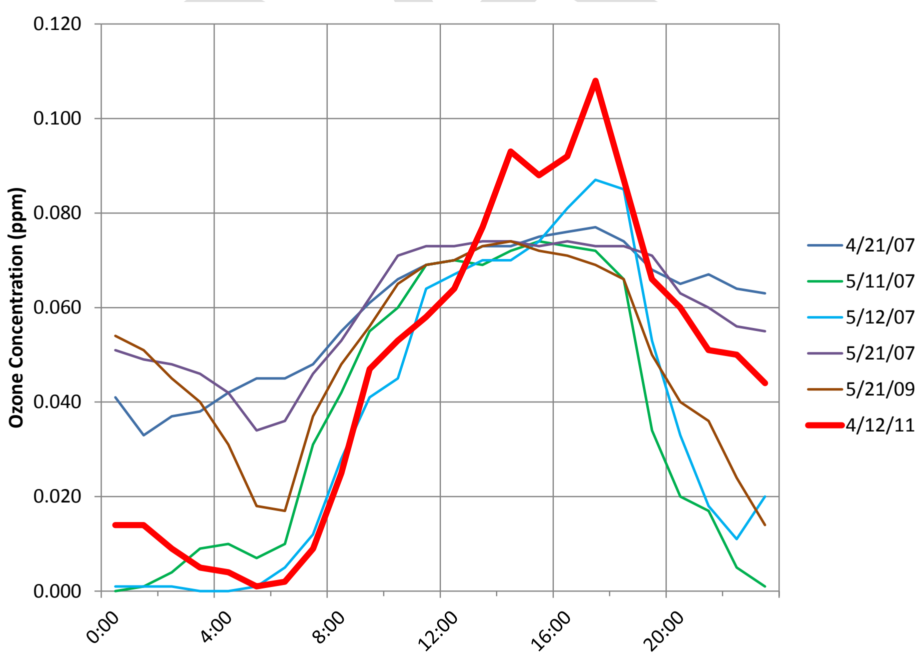


Figure 5-20. Ozone concentrations on April 12, 2011, and historical days with high ozone concentrations but without smoke impacts at KNI-Topeka. Ozone concentrations on April 12, 2011 (thick red line) spiked at distinct hours, likely due to the presence of smoke at the monitor. The historical days with high ozone concentrations had smoother diurnal ozone profiles.

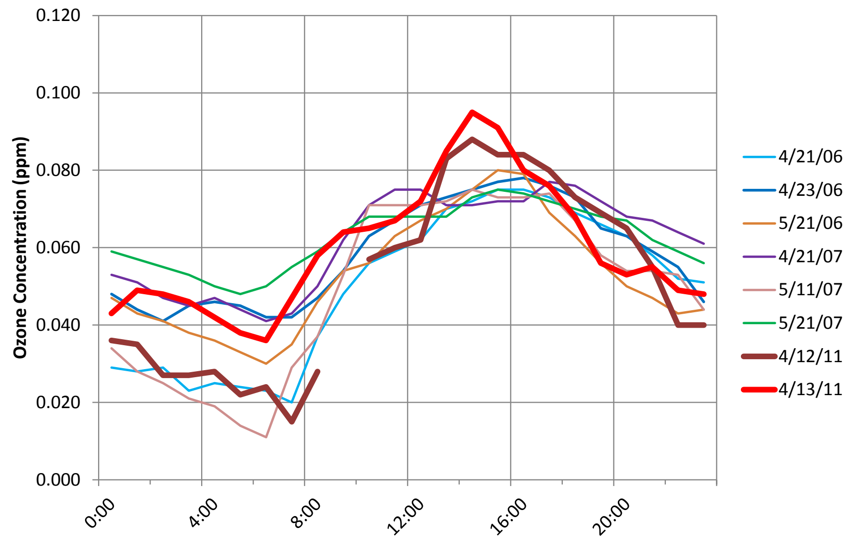


Figure 5-21. Ozone concentrations on April 12 and 13, 2011, and historical days with high ozone levels but without smoke impacts at Konza Prairie. Ozone concentrations on April 12, 2011 (thick brown line) and April 13, 2011 (thick red line) spiked at distinct hours, likely due to the presence of smoke at the monitor. The historical days with high ozone concentrations (thin lines) had smoother diurnal ozone profiles.

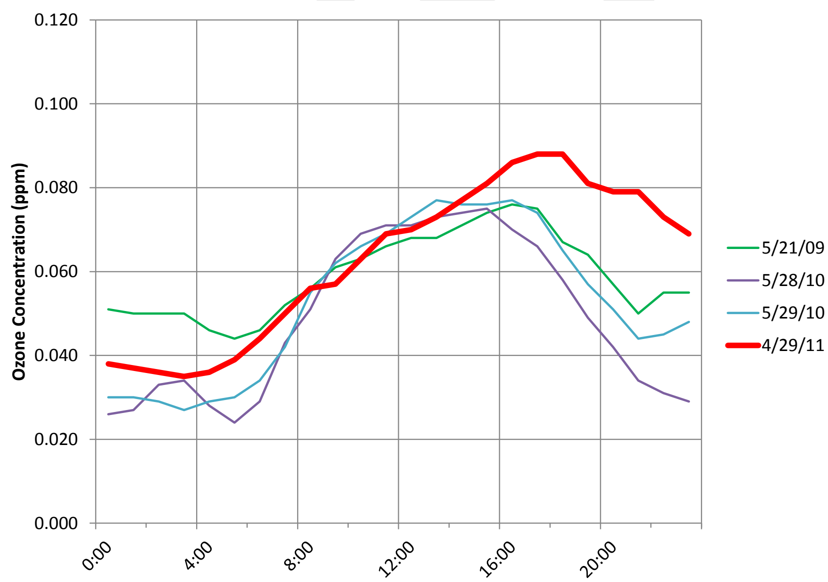


Figure 5-22. Ozone concentrations on April 29, 2011, and historical days with high ozone concentrations but without smoke impacts at Sedgwick. The diurnal ozone profiles on April 29, 2011 (thick red line) and the historical days with high ozone concentrations were relatively smooth. The smoother profile on April 29, 2011, compared to the other smoke-impact days in April 2011 may be the result of enhanced mixing of the smoke plume due to strong winds and plume spread associated with long-range transport.

5.3.3 Temperatures

Temperatures at the smoke-impacted monitors on April 6 and 12, 2011, were much lower than on other days with high ozone concentrations (Table 5-3). Temperatures on April 13 and 29, 2001, were slightly lower than on other days with high ozone concentrations. Since high ozone levels are normally associated with warmer temperatures, the cooler temperatures suggest that ozone enhancement was the result of unusual circumstances, such as a change in emissions (e.g., smoke). It is important to note that the majority of the historical days with high ozone concentrations without smoke impacts occurred in May, which is climatologically warmer than April in Kansas. However, it is notable that ozone concentrations on the four smoke event days in April 2011 were generally higher than on any of the historical high ozone concentration, non-smoke-impact days, despite (1) lower temperatures and (2) roughly one hour less daylight than typical days in mid-May (ozone formation is normally enhanced with a higher sun angle and longer days).

Table 5-3. Daily maximum temperatures, in degrees Fahrenheit, on days with high ozone concentrations in April and May in Kansas.

Monitor	Date in 2011	Daily Maximum Temperature on Smoke-Impact Day	Average Daily Maximum Temperature on Non-Smoke-Impact, High Ozone Days
Mine Creek	April 6	75°	83°
Peck	April 6	73°	84°
Wichita Health Dept.	April 6	73°	87°
KNI-Topeka	April 12	73°	84°
Konza Prairie	April 12	75°	83°
Konza Prairie	April 13	81°	83°
Peck	April 29	81°	84°
Sedgwick	April 29	81°	85°

5.3.4 Spatial Pattern of Ozone

On April 6, 12, and 29, 2001, ozone concentrations were highest in the locations most affected by smoke. On April 13, ozone concentrations were more uniformly elevated across the southern Plains region. **Figures 5-23 through 5-26**, which show peak 8-hour average ozone concentrations on each of the smoke-impact days along with fire and smoke locations, illustrate the following:

- On April 6 (Figure 5-23), ozone concentrations were generally highest at monitors nearest the widespread fires in eastern Kansas and northeastern Oklahoma. Locations further south across Texas and Louisiana had lower ozone concentrations and limited smoke impacts.

- On April 12 (Figure 5-24), ozone concentrations were highest at monitors nearest the widespread fires in eastern Kansas, especially at the KNI-Topeka and Konza Prairie monitors. Areas of limited fire activity, such as Missouri, Arkansas, and Iowa, had lower ozone levels.
- On April 13 (Figure 5-25), ozone concentrations were elevated across much of the southern Plains. In addition to the fires in Kansas, several large fires over northeastern Mexico produced widespread smoke across parts of Texas and Oklahoma. In addition, some smoke produced from fires on April 12 was still present over the region, which likely contributed to regional ozone formation.
- On April 29 (Figure 5-26), smoke from large fires in Texas and Mexico spread northward into Kansas. Ozone concentrations were highest in the vicinity of the denser smoke plumes, which impacted the Dallas-Fort Worth, Oklahoma City, and Wichita metropolitan areas.

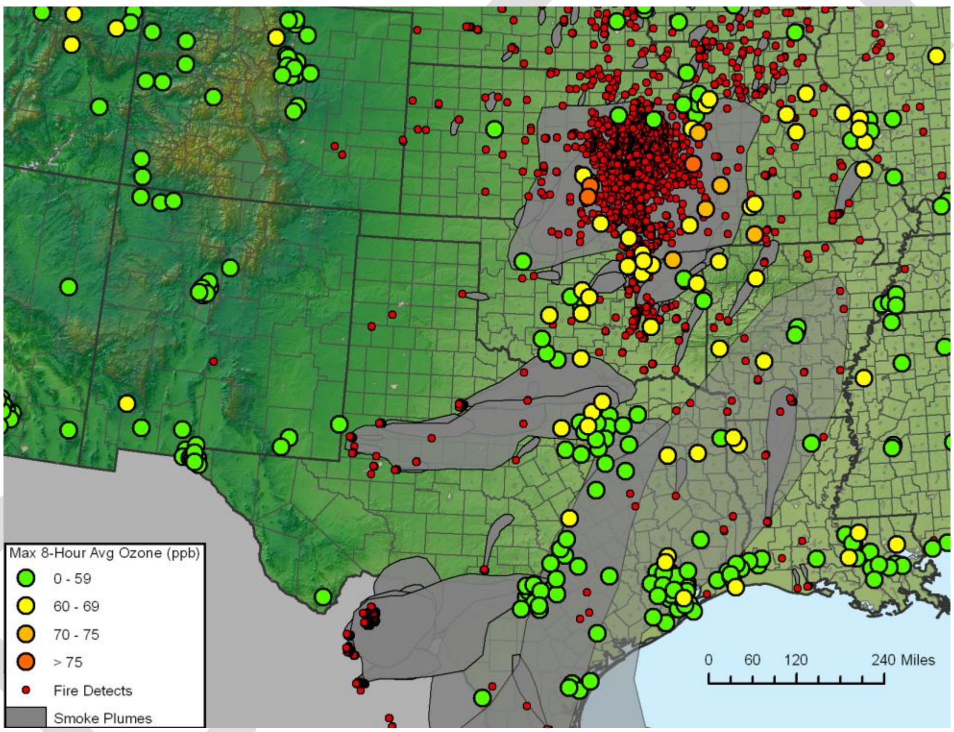


Figure 5-23. Maximum 8-hour ozone concentrations and fire and smoke locations on April 6, 2011. Ozone concentrations were highest near the fires/smoke in the Flint Hills region.

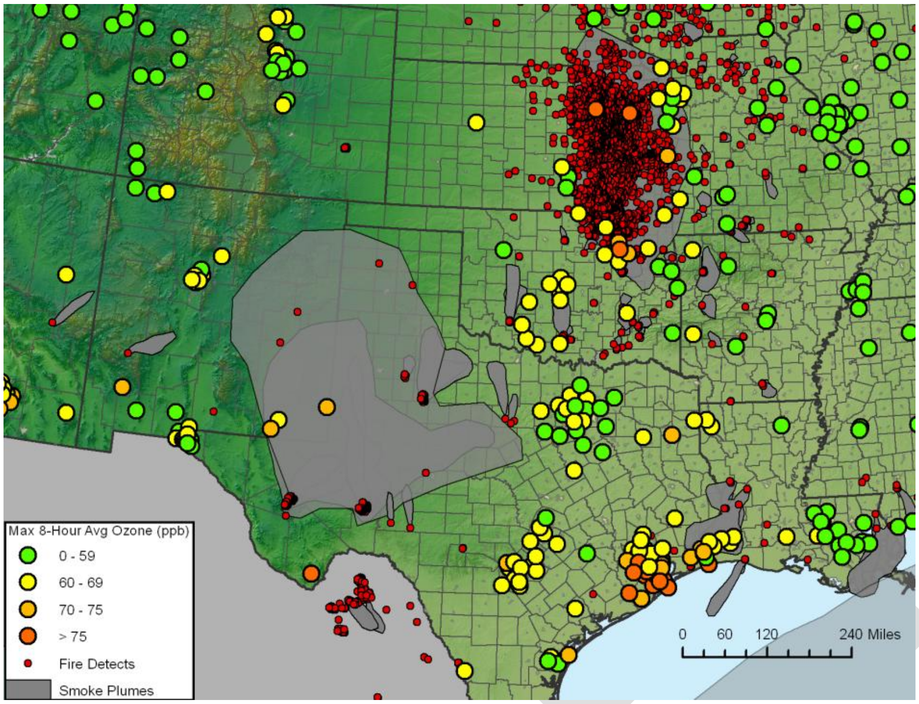


Figure 5-24. Maximum 8-hour ozone concentrations and fire and smoke locations on April 12, 2011. Ozone concentrations were highest near the fires/smoke in the Flint Hills region.

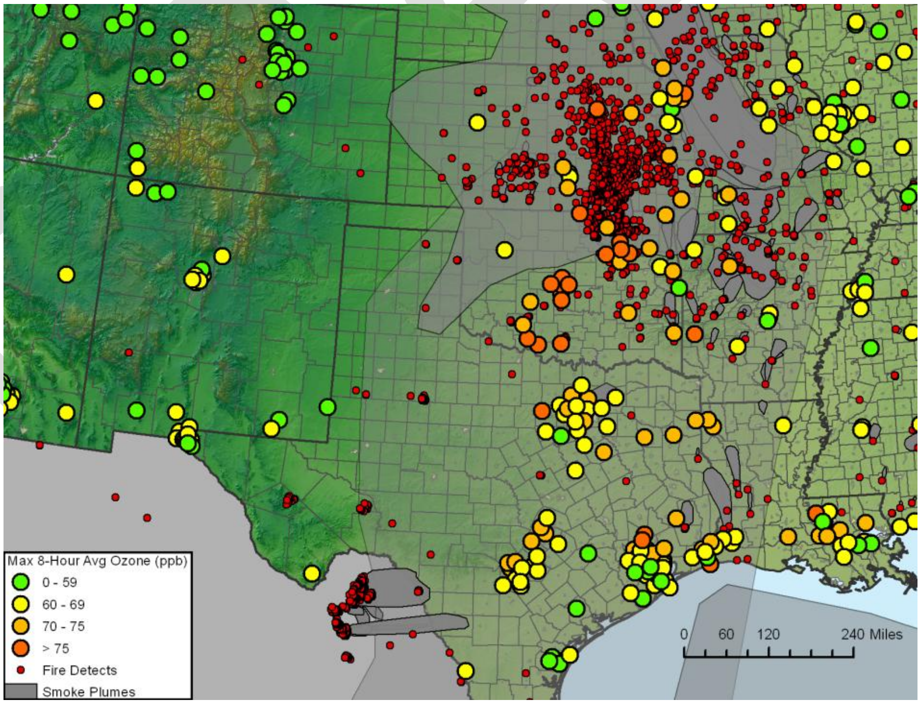


Figure 5-25. Maximum 8-hour ozone concentrations and fire and smoke locations on April 13, 2011. Ozone concentrations were elevated across the region, likely due to widespread smoke.

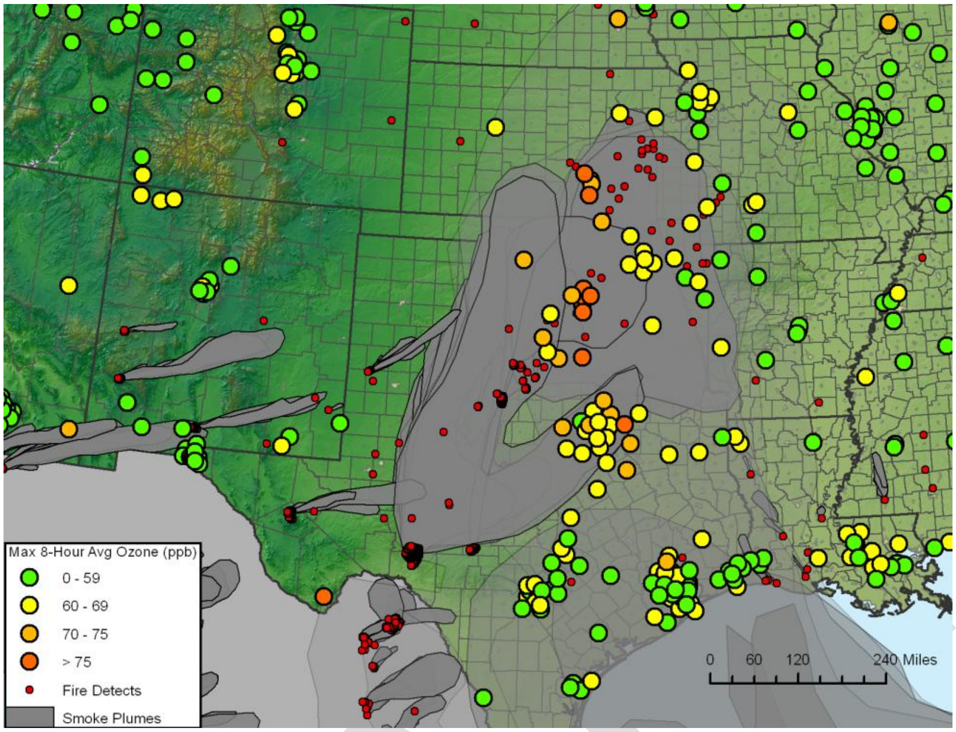


Figure 5-26. Maximum 8-hour ozone concentrations and fire and smoke locations on April 29, 2011. Ozone concentrations were highest in regions affected by smoke from fires occurring in western and northern Texas.

5.3.5 Replace Smoke Impacted Ozone Data from Historical Data

This subsection contains data and discussion on replacing the smoke-affected ozone measurements on April 6, 12, 13, and 29, 2011, with 95th percentile values of ozone concentrations. **Replacing the smoke-affected ozone measurements on the April 2011 smoke-impact days with 95th percentile values results in daily maximum 8-hour ozone concentrations below the standard. This result indicates that the 8-hour ozone concentrations above 0.075 ppm in April 2011 were unusual.**

Figure 5-27 shows the hourly ozone concentrations at Mine Creek on April 6, 2011, compared to selected percentiles of ozone concentrations by hour over the April 2006-2011 period at Mine Creek. Three hours on April 6 (16:00 to 18:00) had ozone concentrations well above the 95th percentile, indicating that those values were historically unusual. **Table 5-4** shows that replacing only the peak 1-hour ozone concentration on April 6, which was likely impacted by smoke, yields an 8-hour ozone concentration below 0.075 ppm.

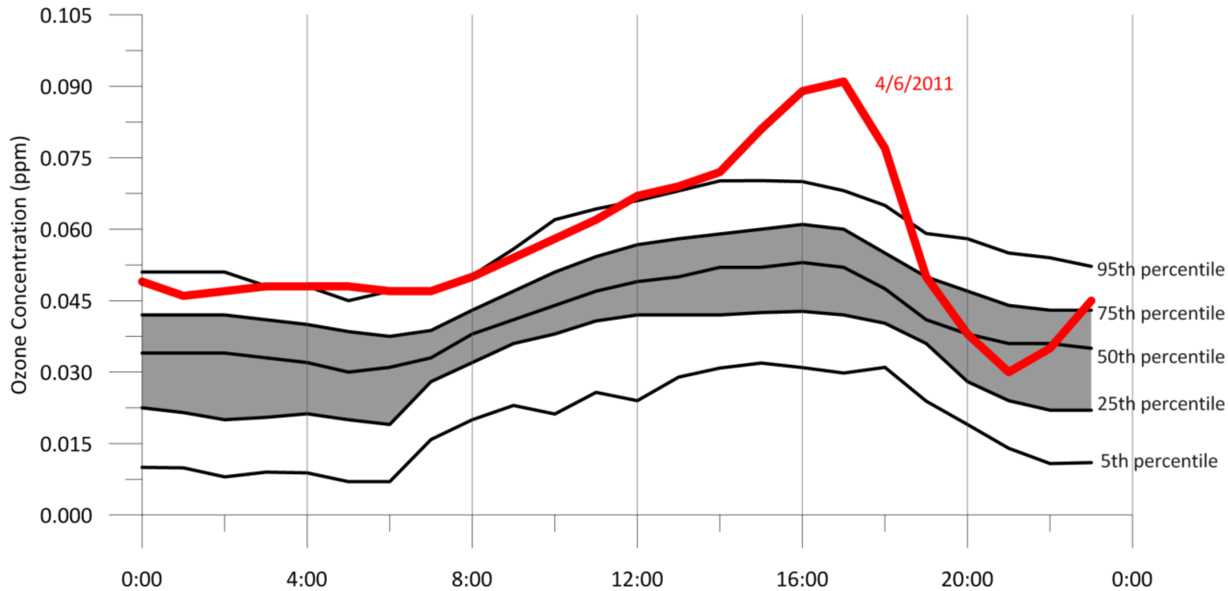


Figure 5-27. Hourly ozone concentrations on April 6, 2011, and selected percentiles of hourly ozone concentrations at Mine Creek. Ozone concentrations on April 6 were above the 95th percentile for several hours.

Table 5-4. Scenarios of 8-hour ozone concentrations on April 6, 2011, at Mine Creek using 95th percentile values.

Scenario	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.076
95^{th} percentile (2006-2011)	0.067
Replace highest smoke-impacted hour with 95^{th} percentile value	0.073
Replace two highest smoke-impacted hours with 95^{th} percentile value	0.070
Replace three highest smoke-impacted hours with 95^{th} percentile value	0.069

Figure 5-28 shows the hourly ozone concentrations at Peck on April 6 and 29, 2011, compared to selected percentiles of ozone concentrations by hour over the April 2006-2011 period at Mine Creek. Ozone concentrations were well above the 95^{th} percentile for several hours on both April 6 and 29, indicating that those ozone levels were historically unusual. **Tables 5-5 and 5-6** show on April 6 and April 29, respectively, that replacing the two highest hourly ozone concentrations, which were likely affected by smoke, would result in 8-hour ozone concentrations below the standard on both days.

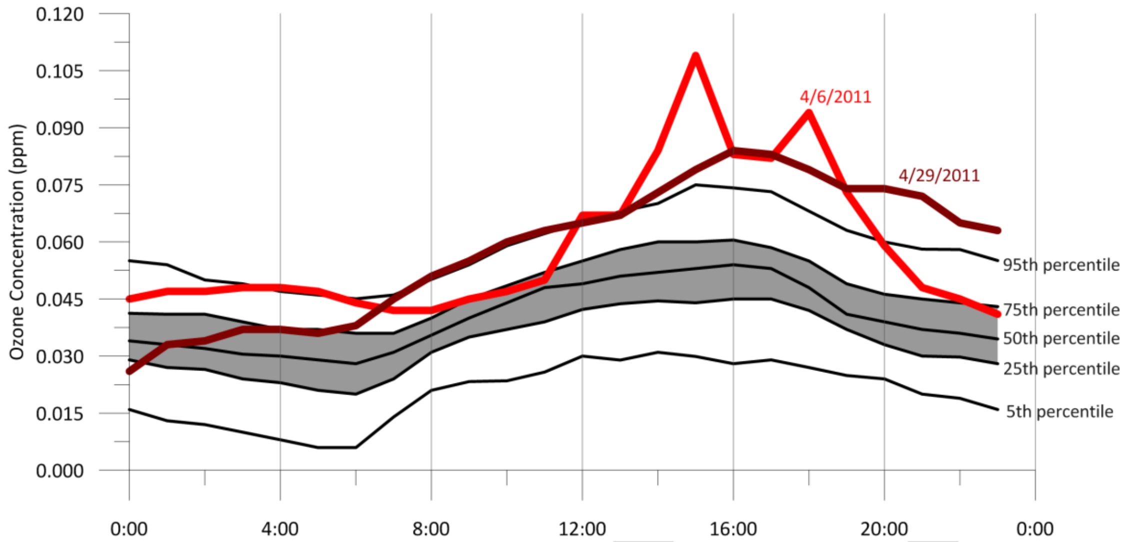


Figure 5-28. Hourly ozone concentrations on April 6 and 29, 2011, and selected percentiles of hourly ozone at Peck. Ozone concentrations on April 6 and 29 were above the 95th percentile for several hours.

Table 5-5. Scenarios of 8-hour ozone concentrations on April 6, 2011, at Peck using 95th percentile values.

Scenario	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.082
95th percentile (2006-2011)	0.068
Replace highest smoke-impacted hour with 95th percentile value	0.078
Replace two highest smoke-impacted hours with 95th percentile value	0.074
Replace three highest smoke-impacted hours with 95th percentile value	0.073

Table 5-6. Scenarios of 8-hour ozone concentrations on April 29, 2011, at Peck using 95th percentile values.

Scenario	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.077
95th percentile (2006-2011)	0.068
Replace highest smoke-impacted hour with 95th percentile value	0.076
Replace two highest smoke-impacted hours with 95th percentile value	0.074
Replace three highest smoke-impacted hours with 95th percentile value	0.074

Figure 5-29 shows the hourly ozone concentrations at Wichita Health Dept. on April 6, 2011, compared to selected percentiles of ozone concentrations by hour over the April 2006-2011 period at Wichita Health Dept. Several hours on April 6 had ozone concentrations well above the 95th percentile, indicating that those ozone levels were unusual compared to historical norms. **Table 5-7** shows that replacing only the highest hourly ozone concentration on April 6, which was likely affected by smoke, would result in an 8-hour ozone concentration below the standard.

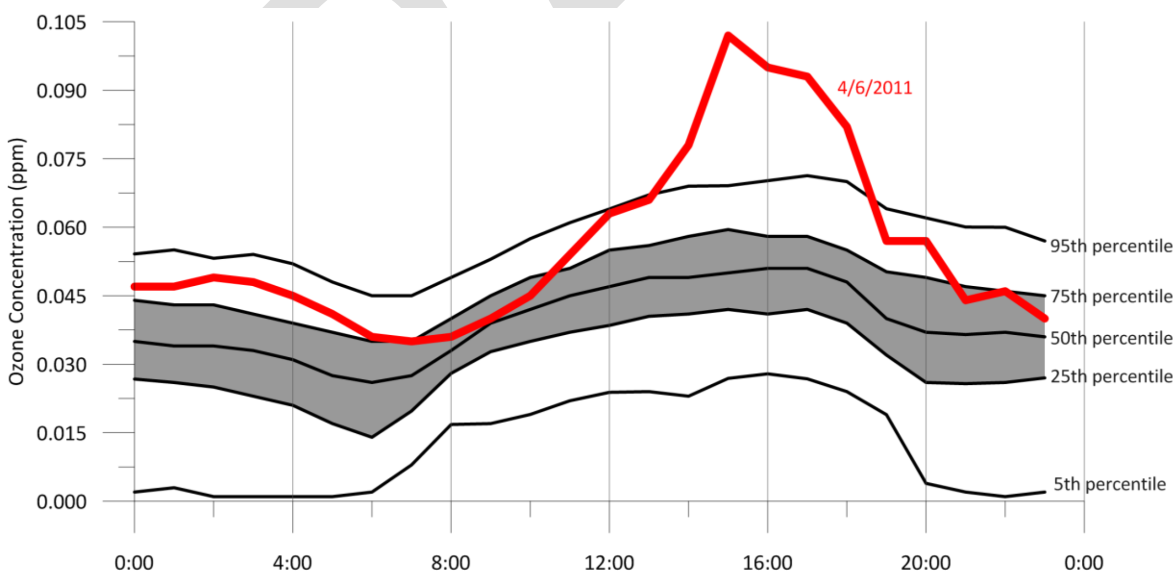


Figure 5-29. Hourly ozone concentrations on April 6, 2011, and selected percentiles of hourly ozone concentrations at Wichita Health Dept. Ozone concentrations on April 6 were above the 95th percentile for several hours.

Table 5-7. Scenarios of 8-hour ozone concentrations on April 6, 2011, at Wichita Health Dept. using 95th percentile values.

Observed	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.079
95th percentile (2006-2011)	0.068
Replace highest smoke-impacted hour with 95th percentile value	0.075
Replace two highest smoke-impacted hours with 95th percentile value	0.072
Replace three highest smoke-impacted hours with 95th percentile value	0.069

Figure 5-30 shows the hourly ozone concentrations at KNI-Topeka on April 12, 2011, compared to selected percentiles of ozone concentrations by hour over the April 2006-2011 period. Several hours on April 12 had ozone concentrations well above the 95th percentile, illustrating that those ozone levels were historically unusual. **Table 5-8** shows that replacing the three highest hourly ozone concentrations on April 12, which were likely affected by smoke, would result in an 8-hour ozone concentration below the standard.

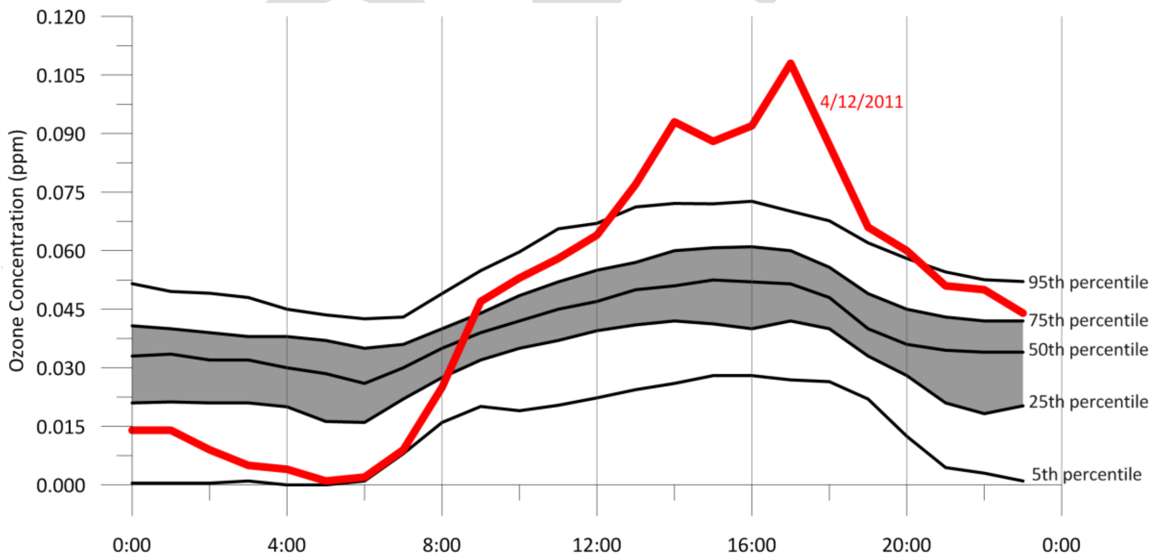


Figure 5-30. Hourly ozone concentrations on April 12, 2011, and selected percentiles of hourly ozone concentrations at KNI-Topeka. Ozone concentrations on April 12 were above the 95th percentile for several hours.

Table 5-8. Scenarios of 8-hour ozone concentrations on April 12, 2011, at KNI-Topeka using 95th percentile values.

Scenario	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.084
95th percentile (2007-2011)	0.068
Replace highest smoke-impacted hour with 95th percentile value	0.079
Replace two highest smoke-impacted hours with 95th percentile value	0.077
Replace three highest smoke-impacted hours with 95th percentile value	0.074

Figure 5-31 shows hourly ozone concentrations at Konza Prairie on April 12 and 13, 2011, compared to selected percentiles of ozone concentrations by hour over the April 2006-2011 period. Several hours on both April 12 and 13 had ozone concentrations well above the 95th percentile, illustrating that those ozone levels were historically unusual. **Table 5-9** shows that replacing the three highest hourly ozone concentrations on April 12 would result in an 8-hour ozone concentration of 0.075 ppm, which is not in exceedance of the 8-hour ozone standard. Satellite imagery and surface weather observations demonstrated that the Konza Prairie monitor was impacted by smoke for a minimum of three hours on April 12. **Table 5-10** shows that replacing the two highest hourly ozone concentrations on April 13 would result in an 8-hour ozone concentration of 0.075 ppm, which is not in exceedance of the 8-hour ozone standard. Surface weather observations demonstrated that the Konza Prairie monitor was impacted by smoke for a minimum of two hours on April 13.

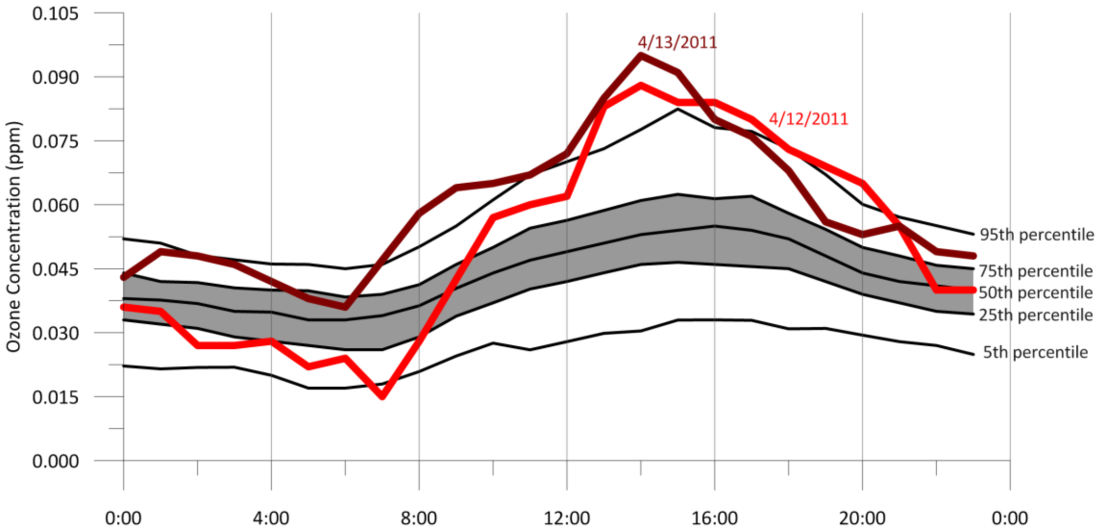


Figure 5-31. Hourly ozone concentrations on April 12 and 13, 2011, and selected percentiles of hourly ozone at Konza Prairie. Ozone concentrations on April 12 and 13 were above the 95th percentile for several hours.

Table 5-9. Scenarios of 8-hour ozone concentrations on April 12, 2011, at Konza Prairie using 95th percentile values.

Scenario	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.078
95th percentile (2006-2011)	0.074
Replace highest smoke-impacted hour with 95th percentile value	0.076
Replace two highest smoke-impacted hours with 95th percentile value	0.076
Replace three highest smoke-impacted hours with 95th percentile value	0.075

Table 5-10. Scenarios of 8-hour ozone concentrations on April 13, 2011, at Konza Prairie using 95th percentile values.

Scenario	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.079
95th percentile (2006-2011)	0.074
Replace highest smoke-impacted hour with 95th percentile value	0.077
Replace two highest smoke-impacted hours with 95th percentile value	0.075
Replace three highest smoke-impacted hours with 95th percentile value	0.074

Figure 5-32 shows the hourly ozone concentrations at Sedgwick on April 29, 2011, compared to selected percentiles of ozone concentrations by hour over the April 2006-2011 period. Ozone concentrations on April 29 were above the 95th percentile for several hours at Sedgwick, indicating that those ozone levels were historically unusual. **Table 5-11** shows that replacing the five highest hourly ozone concentrations on April 29 would result in an 8-hour ozone concentration below the standard. Satellite imagery and PM_{10} concentrations demonstrated that the Sedgwick monitor was affected by smoke for a minimum of five hours.

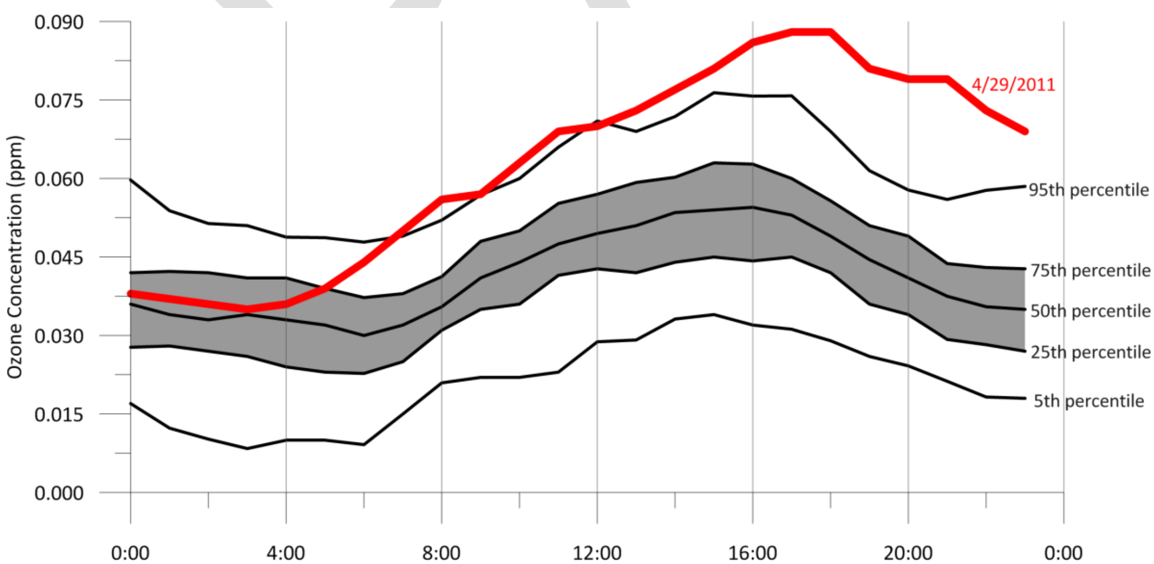


Figure 5-32. Hourly ozone concentrations on April 29, 2011, and selected percentiles of hourly ozone concentrations at Sedgwick. Ozone concentrations on April 29 were in excess of the 95th percentile for several hours.

Table 5-11. Scenarios of 8-hour ozone concentrations on April 29, 2011, at Sedgwick using 95th percentile values.

Scenario	Max 8-Hour Avg Ozone Concentration (ppm)
Observed	0.082
95th percentile (2009-2011)	0.072
Replace highest smoke-impacted hour with 95th percentile value	0.080
Replace two highest smoke-impacted hours with 95th percentile value	0.078
Replace three highest smoke-impacted hours with 95th percentile value	0.077
Replace four highest smoke-impacted hours with 95th percentile value	0.076
Replace five highest smoke-impacted hours with 95th percentile value	0.073

6. But For Demonstration

6.1 Introduction

The purpose of this section is to demonstrate that the 8-hour ozone concentrations above 0.075 ppm on April 6, 12, 13, and 29, 2011, would not have occurred but for the presence of smoke at the impacted monitors (known as a “But For” demonstration). Two analyses were used in this demonstration: (1) analysis of ozone concentrations on days when meteorological conditions were similar but no smoke impacts were present, and (2) analysis of ozone predictions from photochemical model simulations both with and without fires.

6.2 Summary of Results

Table 6-1 summarizes the results of the But For demonstration. **This analysis indicates that the April 2011 8-hour ozone concentrations above 0.075 ppm would not have occurred but for the presence of smoke.** For this demonstration, the estimated ozone contribution due to fires from each method was subtracted from the observed 8-hour ozone concentrations. On all four smoke-event days, the result of that subtraction was less than 0.076 ppm, demonstrating that the observed 8-hour ozone concentrations in exceedance of the NAAQS would not have occurred but for the fires. In addition, because no other unusual emissions were identified on the smoke-event days and because the estimated concentrations without the fires were well below the NAAQS, it is very unlikely that other sources of ozone would have caused the observed high ozone concentrations.

Table 6-1. Summary of results from the But For demonstration. Check marks indicate the analysis demonstrated that 8-hour ozone concentrations would be below the NAAQS but for the smoke.

Date	Monitor	Observed 8-Hour Ozone Concentration (ppm)	8-Hour Ozone Concentration Below NAAQS But For Smoke?	
			Matching Day Analysis	Photochemical Modeling Analysis
4/06/2011	Mine Creek	0.076	*	✓
4/06/2011	Peck	0.082	✓	✓
4/06/2011	Wichita Health Dept.	0.079	✓	✓
4/12/2011	KNI-Topeka	0.084	✓	✓
4/12/2011	Konza Prairie	0.078	✓	✓
4/13/2011	Konza Prairie	0.079	✓	✓
4/29/2011	Peck	0.077	✓	**
4/29/2011	Sedgwick	0.082	✓	**

*No matching day was available for comparison for April 6, 2011, at the Mine Creek monitor.
**Due to long-range smoke transport that occurred on April 29, 2011, the model simulations had difficulty replicating observed ozone levels.

6.3 Matching Days

6.3.1 Methods

To assess whether 8-hour ozone concentrations would not have been above 0.075 ppm "but for" the smoke impacts, ozone concentrations on the smoke-event days were compared to ozone concentrations on days when meteorological conditions were similar but there were no smoke impacts. Only days in April and May in the years 2006-2011 were used in this analysis, to account for seasonal and emissions representativeness. The historical days were first filtered quantitatively for conditions similar to the four smoke-event days. The parameters chosen for comparison are standard meteorological observations representing surface and upper-level conditions, including daily high temperature, surface wind speeds, and 500 mb geopotential heights; these parameters characterize the basic meteorological conditions that affect ozone formation. The resulting potential matches were then filtered by qualitative analysis of surface and upper-level weather patterns. The days with meteorologically matching conditions were finally filtered for smoke impact; days when smoke may have impacted the monitor were not considered. Smoke impact was assessed using satellite imagery, fire location data, and trajectory analysis.

When a reasonable match was identified, 8-hour ozone concentrations on the smoke-impact day and the matching day were compared at the affected monitors. If the 8-hour ozone concentration was not above 0.075 ppm on the matching day, it is unlikely that 8-hour ozone concentrations would have been above 0.075 ppm on the smoke-impact day in the absence of smoke. The following subsections describe the meteorological conditions and ozone concentrations on the meteorologically matching days for each of the four smoke-event days in April 2011. A more detailed description of meteorological conditions on the smoke-event days themselves can be found in Section 4 (Causal Relationship) of this report.

6.3.2 Matching Day Results

Smoke Event Day: April 6, 2011
Matching Day: April 6, 2008
Impacted Monitors: Peck and Wichita Health Dept. (Wichita area)
Mine Creek (southeast Kansas)

Summary: One day without smoke impacts, but with meteorological conditions similar to those on April 6, 2011, was identified for the Peck and Wichita Health Dept. monitors. The maximum 8-hour average ozone concentrations at the Peck and Wichita Health Dept. monitors on the matching day were well below the federal 8-hour ozone standard (0.053 ppm and 0.051 ppm, respectively). Thus, it is unlikely that the 8-hour ozone concentrations above 0.075 ppm would have occurred on the smoke-event day in the absence of smoke at those two monitors. For the Mine Creek monitor, no matching day without smoke impacts was available for comparison.

Large-Scale Pattern: April 6, 2008, was identified as a good meteorological matching day with limited smoke impact at the two Wichita-area monitors (Peck and Wichita Health Dept.). **Figures 6-1 and 6-2** show the 500 mb patterns on the smoke-event and matching days, respectively. **Figures 6-3 and 6-4** show the surface patterns on the smoke-event and matching days, respectively. While the 500 mb pattern shows a trough over the central United States on the smoke-event day and a more-zonal flow on the matching day, the surface maps are quite similar, with a cold front bisecting Kansas and a broad surface high pressure system over the Tennessee River Valley.

Local Conditions – Wichita Area: Surface high and low temperatures observed in Wichita were very similar on the smoke-event and matching days, as were 850 mb temperatures at the nearest representative sounding (**Table 6-2**). Skies were also mostly sunny over Wichita on both days. Surface winds on the smoke-event and matching days were in very good agreement, with a clear shift from moderate southerly winds in the morning to moderate northerly winds in the afternoon. On the matching day, numerous fires were burning in the Flint Hills region east of Wichita; however, trajectory and satellite analysis indicated that smoke from these fires did not impact the Wichita area monitors on the matching day.

Local Conditions – Mine Creek Area: April 6, 2008, was not as useful a matching day for conditions at Mine Creek because of substantial cloud cover and possible impacts from Flint Hills fires. No other days in the historical data set were identified as good meteorological matches for conditions near the Mine Creek monitor. Therefore, the matching day analysis was not used to support the But For demonstration for the 8-hour ozone concentration at Mine Creek on April 6, 2011.

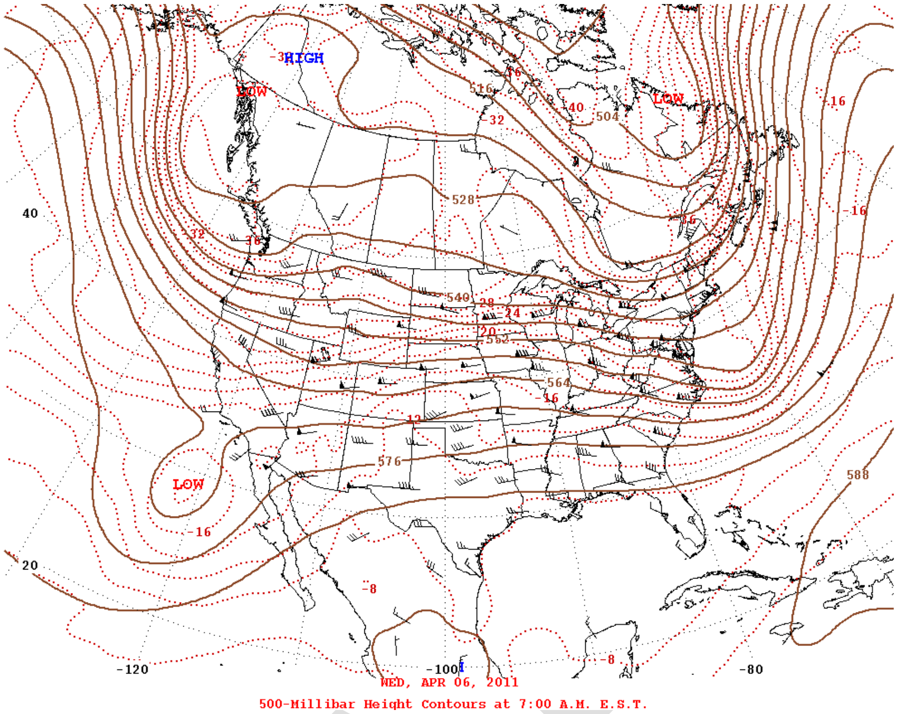


Figure 6-1. Plot of 500 mb heights for 06:00 on April 6, 2011 (Smoke-Event Day), showing a weak upper-level ridge of high pressure over eastern Kansas. Source: NWS.

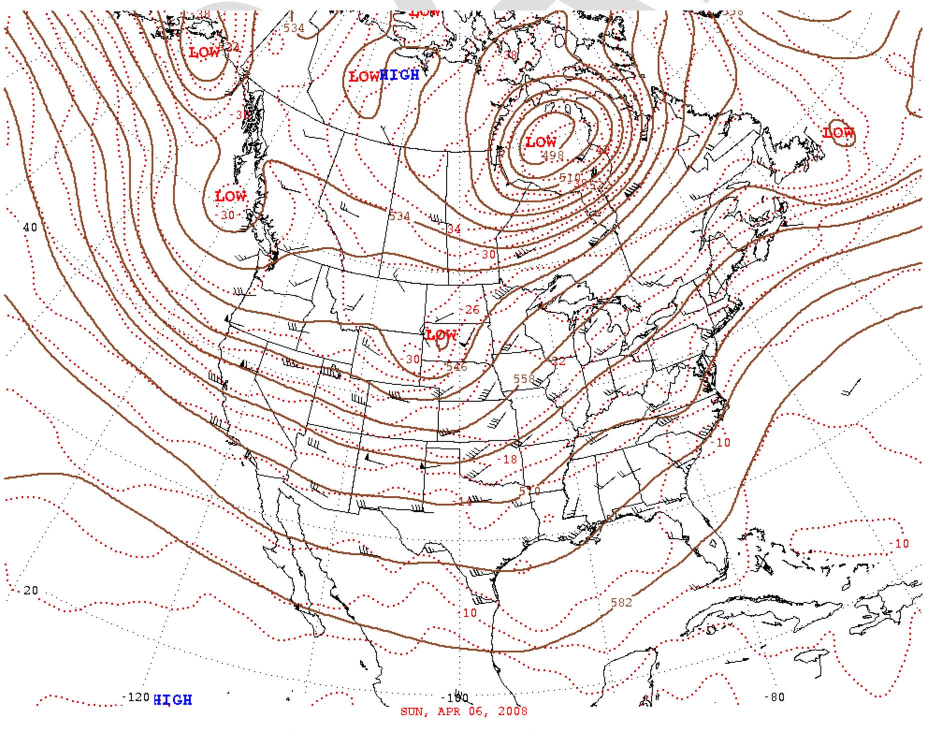


Figure 6-2. 500 mb heights for 06:00 on April 6, 2008 (Matching Day), showing a trough of low pressure approaching eastern Kansas. Source: NWS.

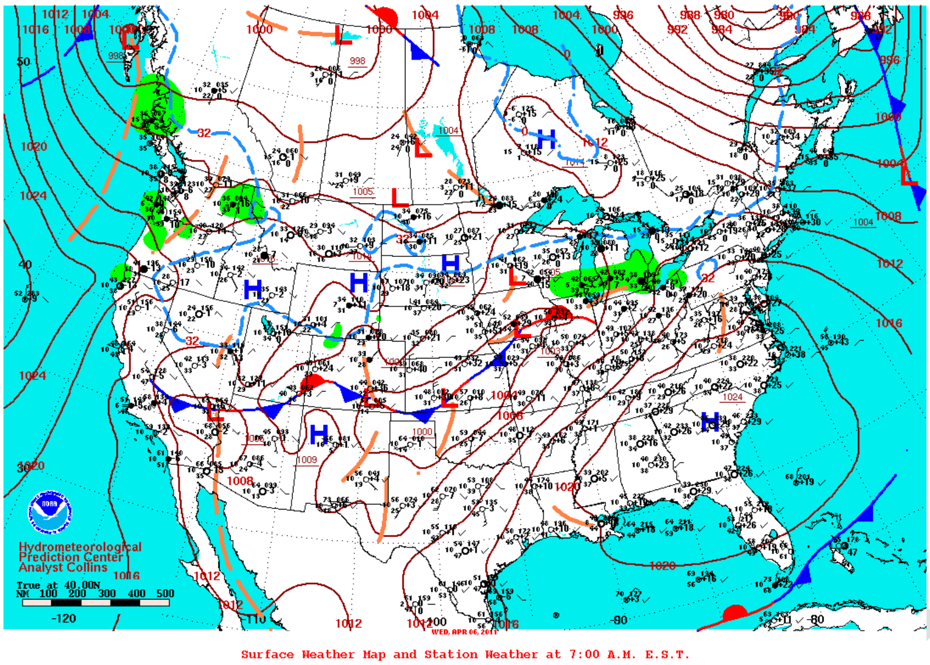


Figure 6-3. Surface map for 06:00 on April 6, 2011 (Smoke-Event Day), showing a cold front over Kansas, with southerly winds ahead of the front and northerly winds behind the front. Source: NWS.

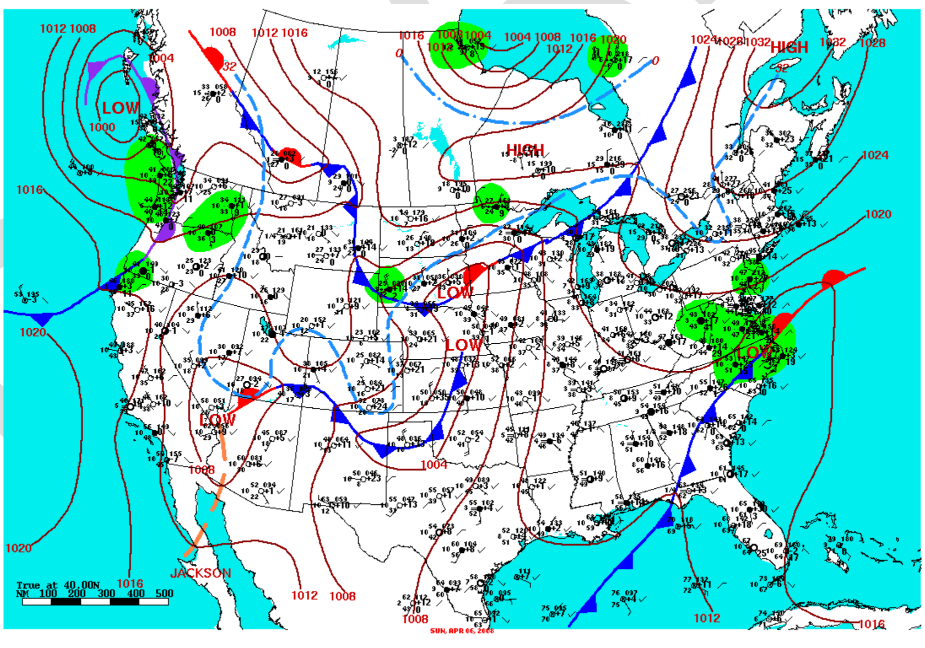


Figure 6-4. Surface map for 06:00 on April 6, 2008 (Matching Day), showing a cold front over Kansas, with southerly winds ahead of the front and northerly winds behind the front. Source: NWS.

Table 6-2. Meteorological conditions and 8-hour ozone concentrations on April 6, 2011 and April 6, 2008. Meteorological conditions on the matching and smoke-event days were very similar, but ozone concentrations at the Wichita-area monitors on the matching day were lower and were below the federal 8-hour ozone standard.

Parameter	April 6, 2011 (Smoke Event Day)	April 6, 2008 (Matching Day)
Wichita High Temp (°F)	73	72
Wichita Low Temp (°F)	54	50
Wichita 6 a.m. to 12 p.m. Wind Speed (kts)	12.6	11.3
Wichita 6 a.m. to 12 p.m. Wind Direction (°)	187	199
Wichita 12 to 6 p.m. Wind Speed (kts)	13.2	13.5
Wichita 12 to 6 p.m. Wind Direction (°)	6	338
Chanute High Temp (°F)	75	73
Chanute Low Temp (°F)	54	48
Chanute 6 a.m. to 12 p.m. Wind Speed (kts)	15.6	11.7
Chanute 6 a.m. to 12 p.m. Wind Direction (°)	189	169
Chanute 12 to 6 p.m. Wind Speed (kts)	9.9	10.1
Chanute 12 to 6 p.m. Wind Direction (°)	223	236
Topeka 12Z 850 Temp (°C)	11.8	12.2
Topeka 12Z 500 mb Height (m)	5670	5590
Solar Radiation	NA	NA
Surface Pattern	Cold front across Kansas, high pressure east	Cold front across Kansas
500 mb Pattern	Flat ridge over Kansas	Trough over Kansas
Cloud Cover	Mostly sunny with passing cirrus	Mostly sunny over Wichita monitors; mostly cloudy over Mine Creek
Mine Creek 8-hour Ozone (ppm)	0.076	0.062*
Peck 8-hour Ozone (ppm)	0.082	0.053
Wichita 8-hour Ozone (ppm)	0.079	0.051

*The matching day showed some smoke impact at the Mine Creek monitor and thus should not be used to support the But For demonstration.

Smoke Event Day: April 12, 2011
Matching Days: April 27, 2006 (Matching Day 1)
May 4, 2008 (Matching Day 2)
Impacted Monitors: Konza Prairie and KNI-Topeka

Summary: Two days with meteorological conditions similar to those on the smoke-event day were identified. The 8-hour ozone concentrations on the matching days at KNI-Topeka (0.056 ppm) and Konza Prairie (0.059 ppm and 0.063 ppm) were much lower than the federal 8-hour ozone standard on the matching days. Thus, given the similar meteorological conditions at the impacted monitors at the smoke-event days, it is unlikely that the 8-hour ozone concentrations above 0.075 ppm would have occurred on April 12, 2011, but for the smoke impact.

Large-Scale Pattern: On the morning of April 12, 2011, a 500 mb ridge was positioned over the central and southern Plains (**Figure 6-5**). Matching Day 1 had a similar 500 mb pattern (**Figure 6-6**), with a ridge of high pressure over the southern Plains and troughs of low pressure over the western and eastern regions of the United States. Matching Day 2 had a weaker 500 mb ridge that was slightly farther west than that of the smoke-event day (**Figure 6-7**). At the surface, a high-pressure system was over eastern Kansas on the smoke-event day (**Figure 6-8**) and on the matching days (**Figures 6-9 and 6-10**).

Local Conditions: Overall, surface high and low temperatures at Topeka (representative of the KNI-Topeka monitor) and Manhattan (representative of the Konza Prairie monitor) were very similar on the smoke-event day and both matching days (**Table 6-3**). Skies were sunny to mostly sunny over the two impacted monitors on the smoke-event day and both matching days; likewise, solar radiation observations at Konza Prairie were similar on the smoke-event and matching days. Surface winds on the smoke-event day and matching days were qualitatively in agreement, with light winds during the morning and winds increasing from the south in the afternoon. However, winds were slightly stronger on the two matching days than on the smoke-event day.

On Matching Day 1, visible satellite imagery indicated some smoke from fires south of Topeka moving northward, staying east of Konza Prairie but possibly impacting the KNI-Topeka in the late afternoon. On Matching Day 2, smoke was not apparent on satellite imagery, but analysis of fire and smoke data and trajectories indicate some potential smoke impact due to fires south of the impacted monitors. However, on both matching days, the smoke appears much less widespread and the fires are less numerous on the matching day compared to the smoke-event day. In addition, hourly PM_{10} concentrations at KNI-Topeka were low (<50 $\mu g/m^3$) on Matching Day 2 (PM_{10} data from KNI-Topeka were not available for Matching Day 1), and, unlike the smoke-event day, no afternoon visibility restrictions were reported at Topeka and Manhattan on the two matching days.

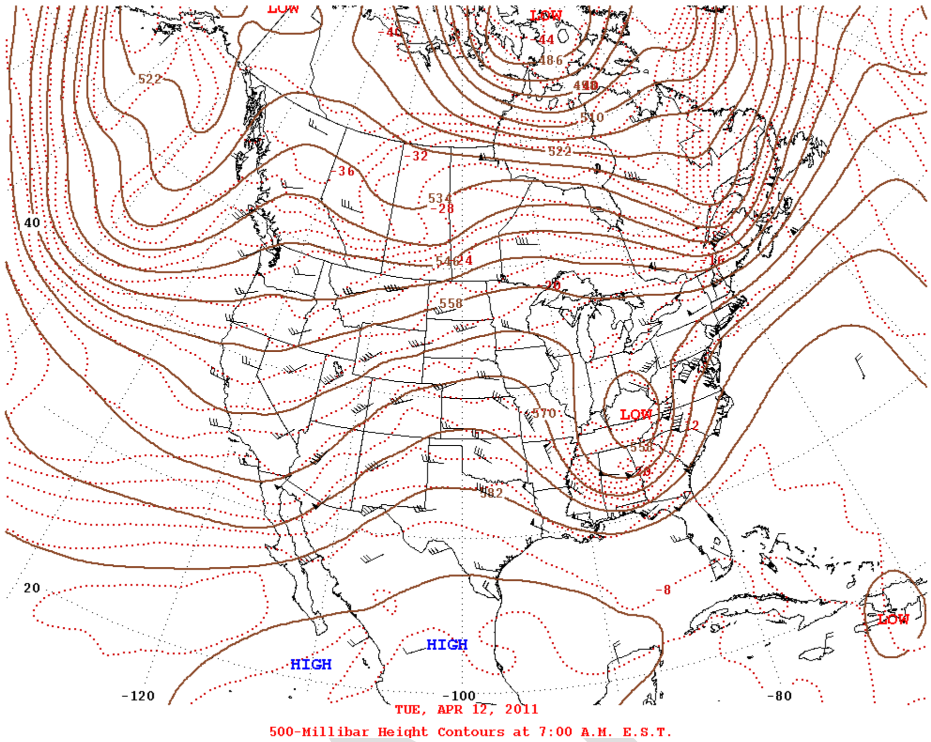


Figure 6-5. 500 mb heights for 06:00 on April 12, 2011 (Smoke Event Day), showing a ridge of high pressure over Kansas. Source: NWS.

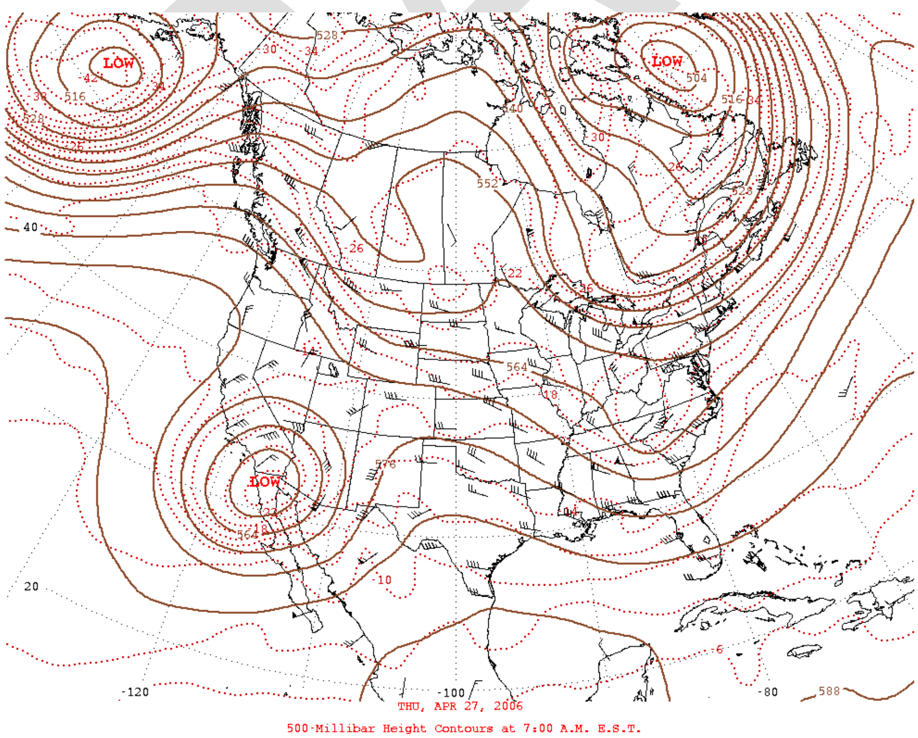


Figure 6-6. 500 mb heights for 06:00 on April 27, 2006 (Matching Day 1), showing a ridge of high pressure over Kansas. Source: NWS.

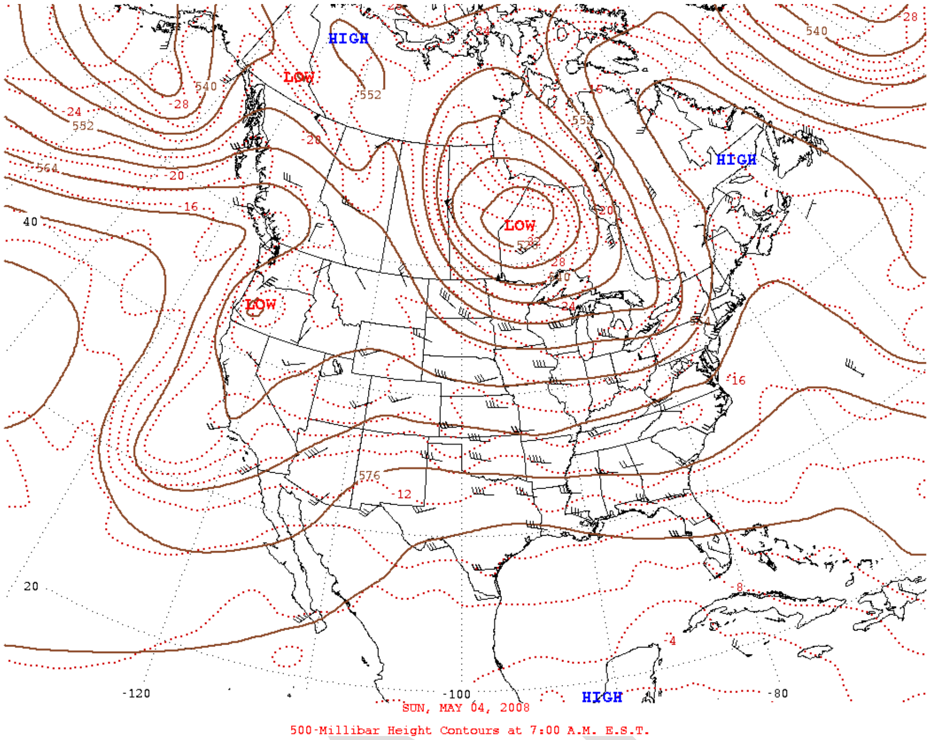


Figure 6-7. 500 mb heights for 06:00 on May 4, 2008 (Matching Day 2), showing a ridge of high pressure west of Kansas with a trough of low pressure east. Source: NWS.

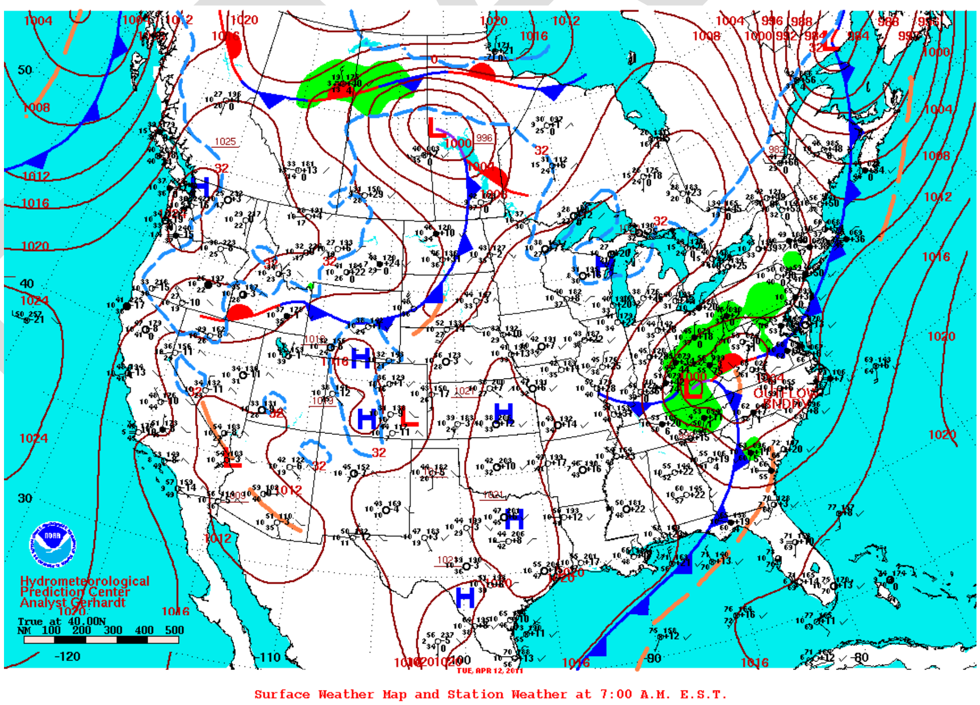


Figure 6-8. Surface map for 06:00 on April 12, 2011 (Smoke Event Day), showing high pressure over the southern Plains. Source: NWS.

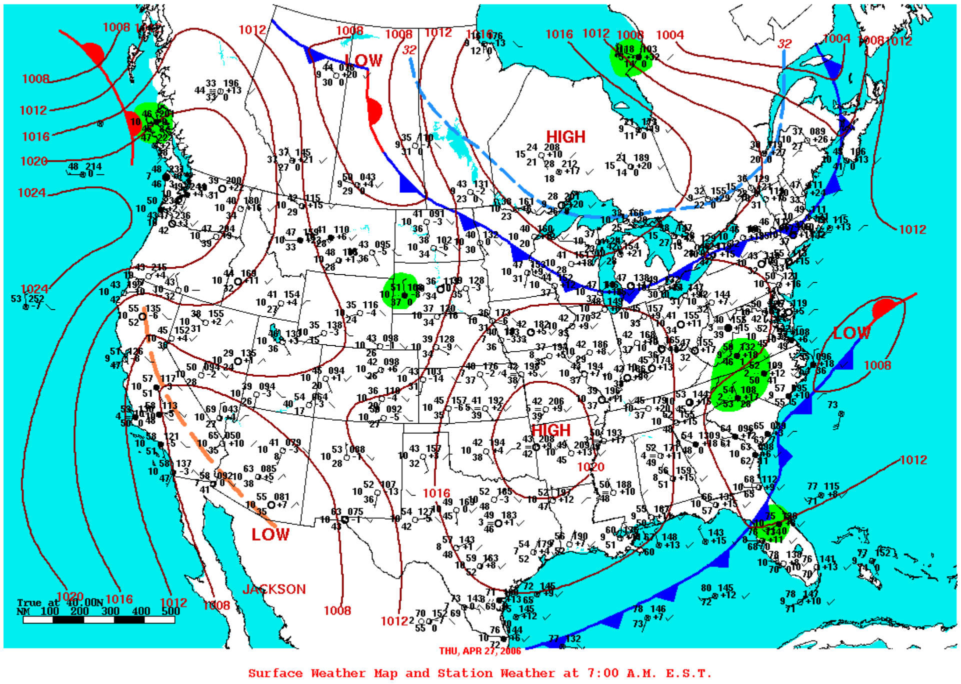


Figure 6-9. Surface map for 06:00 on April 27, 2006 (Matching Day 1), showing high pressure over the southern Plains. Source: NWS.

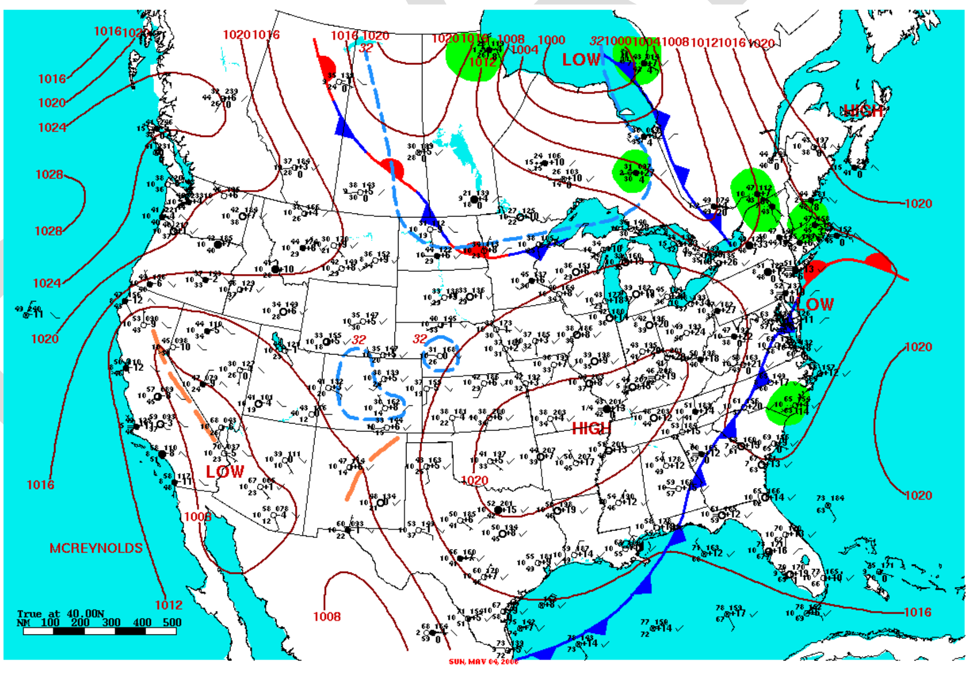


Figure 6-10. Surface map for 06:00 on May 4, 2008 (Matching Day 2), showing high pressure over the southern Plains eastward to the Ohio Valley. Source: NWS.

Table 6-3. Meteorological conditions and 8-hour ozone concentrations on April 12, 2011, and associated matching days. Meteorological conditions on the smoke-event day and two matching days were similar, but ozone concentrations on the two matching days were lower than on the smoke-event day and were below the federal 8-hour ozone standard.

Parameter	April 12, 2011 (Smoke Event Day)	April 27, 2006 (Matching Day 1)	May 4, 2008 (Matching Day 2)
Topeka High Temp (°F)	73	72	72
Topeka Low Temp (°F)	37	37	36
Topeka 6 a.m. to 12 p.m. Wind Speed (kts)	0	1.9	0.7
Topeka 6 a.m. to 12 p.m. Wind Direction (°)	–	212	240
Topeka 12 to 6 p.m. Wind Speed (kts)	4.1	6.7	6.5
Topeka 12 to 6 p.m. Wind Direction (°)	166	176	214
Manhattan High Temp (°F)	75	73	73
Manhattan Low Temp (°F)	34	36	28
Manhattan 6 a.m. to 12 p.m. Wind Speed (kts)	1.1	4.0	2.3
Manhattan 6 a.m. to 12 p.m. Wind Direction (°)	193	198	235
Manhattan 12 to 6 p.m. Wind Speed (kts)	6.7	12.8	8.8
Manhattan 12 to 6 p.m. Wind Direction (°)	216	178	214
Konza Prairie average solar radiation (W/m^2)	540	578	609
Topeka 12Z 850 Temp (°C)	5.4	8.0	5.8
Topeka 12Z 500 mb Height (m)	5720	5700	5660
Cloud Cover	Sunny with cirrus clouds after 5 p.m.	Sunny, a few passing cirrus	Sunny
Surface Pattern	Surface high over Kansas, moving east	Surface high just east of Kansas	Surface high east of Kansas
500 mb Pattern	Ridge over Kansas	Ridge building over Kansas	Weak trough east of Kansas, weak ridge west
KNI-Topeka (ppm)	0.084	*	0.059
Konza Prairie (ppm)	0.078	0.056	0.063

* The KNI-Topeka monitor was not in service until 2007

Smoke Event Day: April 13, 2011
Matching Day: April 5, 2006
Impacted Monitor: Konza Prairie

Summary: One day with meteorological conditions similar to those on April 13, 2011, but with limited smoke impacts, was identified. The 8-hour ozone concentration on the matching day at Konza Prairie was 0.061 ppm, which is lower than the federal 8-hour ozone standard. Thus, it is unlikely that the 8-hour ozone concentration would have exceeded 0.075 ppm on April 13, 2011, but for the smoke.

Large-Scale Pattern: On both the smoke-event day (**Figure 6-11**) and the matching day (**Figure 6-12**), a 500 mb ridge of high pressure was located over the central United States. At the surface on the smoke-event day, a low-pressure system was developing along a stationary front over western Kansas, with a broad high-pressure system east of Kansas (**Figure 6-13**). On the matching day, a surface low-pressure system was developing west of Konza Prairie with a high-pressure system to the east, similar to conditions on the smoke-event day (**Figure 6-14**). A warm front was located over western Kansas extending southward into Texas on the matching day; this is a different frontal configuration than on the smoke-event day.

Local Conditions: With the exception of slightly stronger morning wind speeds on the matching day, winds and temperatures were quite similar on the smoke-event day and the matching days (**Table 6-4**). On both days, southerly winds increased from the morning to the afternoon.

Fire and smoke data indicated some burning south of Konza Prairie on the matching day, but much less than on the 2011 smoke-event day. However, smoke was difficult to detect on satellite imagery because of cirrus clouds over the region on both the smoke-event and matching days.

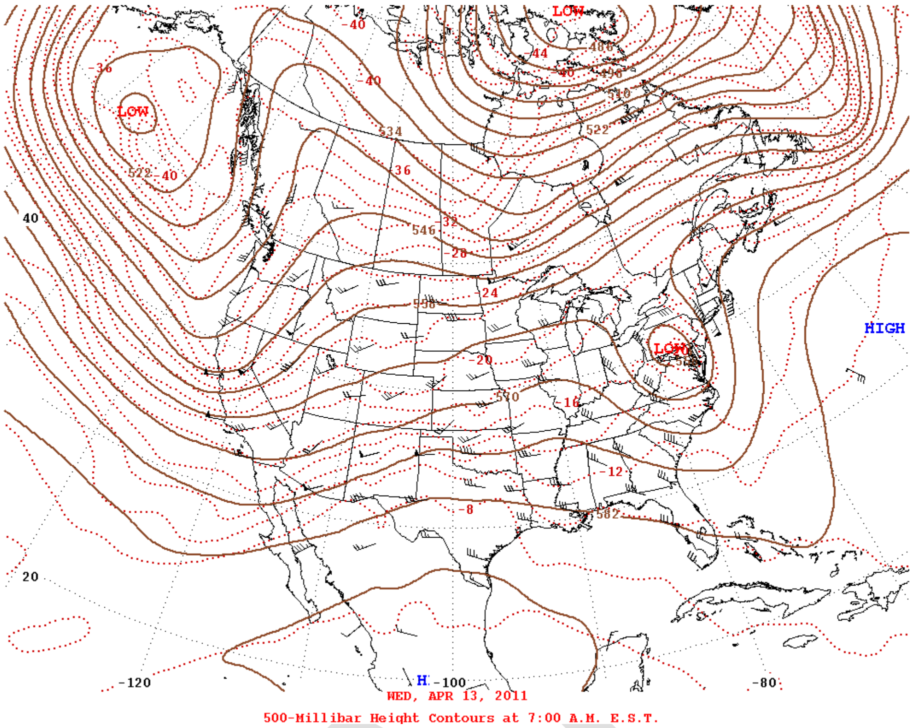


Figure 6-11. 500 mb heights for 06:00 on April 13, 2011 (Smoke Event Day), showing a ridge of high pressure over the central United States. Source: NWS.

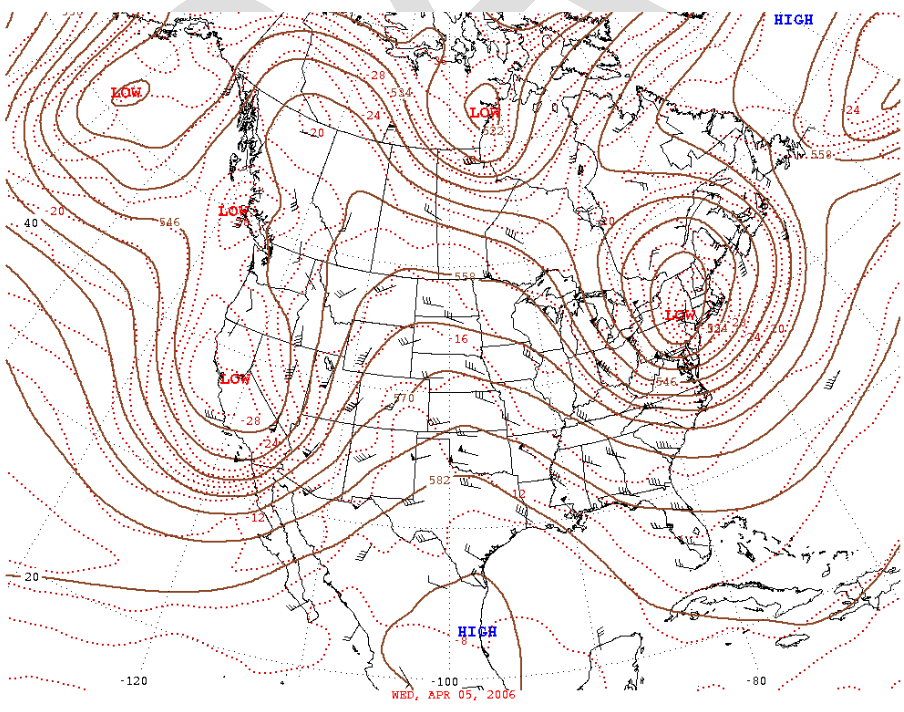
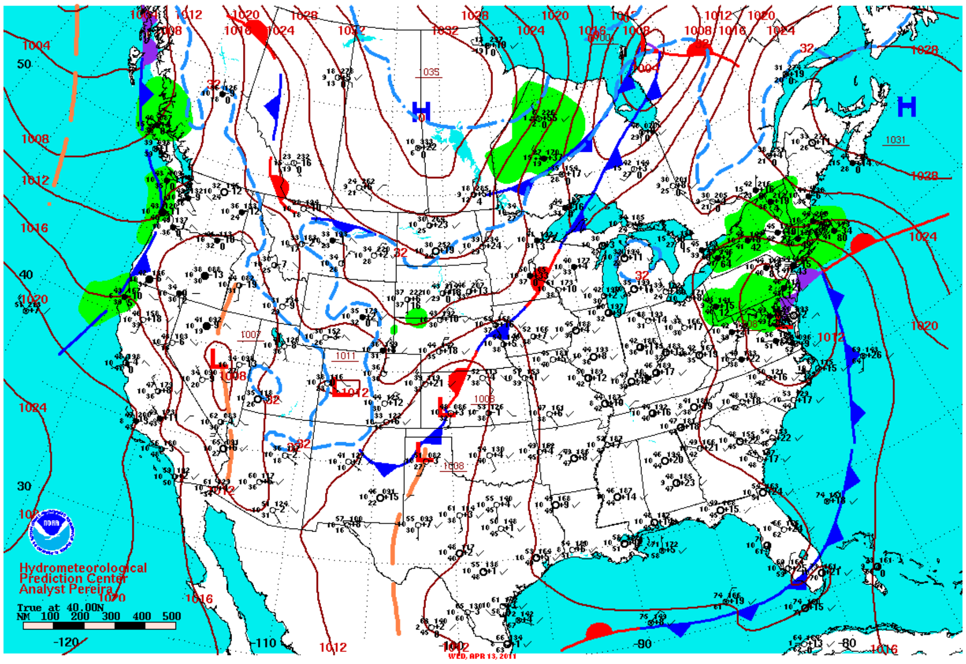
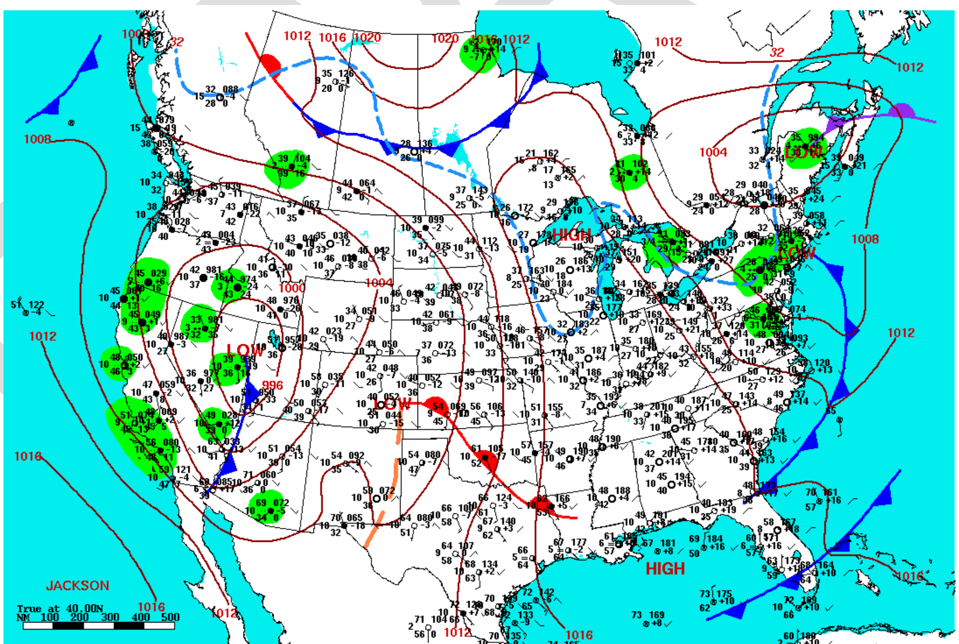


Figure 6-12. 500 mb heights for 06:00 on April 5, 2006 (Matching Day), showing a ridge of high pressure over the central United States. Source: NWS.



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

Figure 6-13. Surface map for 06:00 on April 13, 2011 (Smoke-Event Day), showing low pressure over western Kansas with high pressure over the Mississippi Valley. Source: NWS.



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

Figure 6-14. Surface map for 06:00 on April 5, 2006 (Matching Day), showing a weak low-pressure system west of Kanas and a warm front extending southeastward into Texas. Source: NWS.

Table 6-4. Meteorological conditions and 8-hour ozone concentrations on April 13, 2011, and April 5, 2006. Meteorological conditions were similar on both days, but ozone concentrations on the matching day were lower and were well below the federal 8-hour ozone standard.

Parameter	April 13, 2011 (Smoke-Event Day)	April 5, 2006 (Matching Day)
Manhattan High Temp (°F)	81	82
Manhattan Low Temp (°F)	52	48
Manhattan 6 a.m. to 12 p.m. Wind Speed (kts)	3.1	6.3
Manhattan 6 a.m. to 12 p.m. Wind Direction (°)	173	165
Manhattan 12 to 6 p.m. Wind Speed (kts)	13.3	13.1
Manhattan 12 to 6 p.m. Wind Direction (°)	160	174
Konza Prairie average solar radiation (W/m^2)	339	435
Topeka 12Z 850 Temp (°C)	11.8	13.6
Topeka 12Z 500 mb Height (m)	5700	5720
Cloud Cover	Cirrus most of day	Cirrus most of day
Surface Pattern	Surface high east of Kansas, weak low west	Surface high east of Kansas, weak low west
500 mb Pattern	Weak ridge over Kansas	Ridge over Kansas
Konza Prairie (ppm)	0.079	0.061

Smoke Event Day: April 29, 2011
Matching Days: May 12, 2008 (Matching Day 1)
May 4, 2011 (Matching Day 2)
Impacted Monitors: Peck and Sedgwick (both in Wichita area)

Summary: Two days having meteorological conditions similar to those on April 29, 2011, but without smoke impacts, were identified. The 8-hour ozone concentrations on the matching days at Peck (0.057 ppm and 0.062 ppm) and at Sedgwick (0.055 ppm and 0.056 ppm) were well below the NAAQS. Thus, it is unlikely that the 8-hour ozone concentrations above 0.075 ppm would have occurred on April 29, 2011, but for the impact of smoke on the monitors.

Large-Scale Pattern: On the smoke-event day (**Figure 6-15**), Matching Day 1 (**Figure 6-16**), and Matching Day 2 (**Figure 6-17**), a 500 mb ridge of high pressure was located over the Plains states. The surface patterns on the smoke-event day (**Figure 6-18**) and matching days (**Figures 6-19 and Figure 6-20**) all showed moderately strong southerly gradients over Kansas.

Local Conditions: Meteorological conditions in Wichita on the smoke-event day and matching days were very similar (**Table 6-5**). On each day, southerly winds were moderate to strong in the afternoon; the southerly winds were stronger on the smoke-event day, although stronger winds would ordinarily enhance pollutant dispersion. Skies were sunny on the smoke-event day and matching days.

Fire data and satellite imagery did not indicate smoke in the Wichita area on the matching days. Several fires were indicated over the Flint Hills region on Matching Day 2, but winds were not favorable for transport of smoke from those fires into the Wichita area.

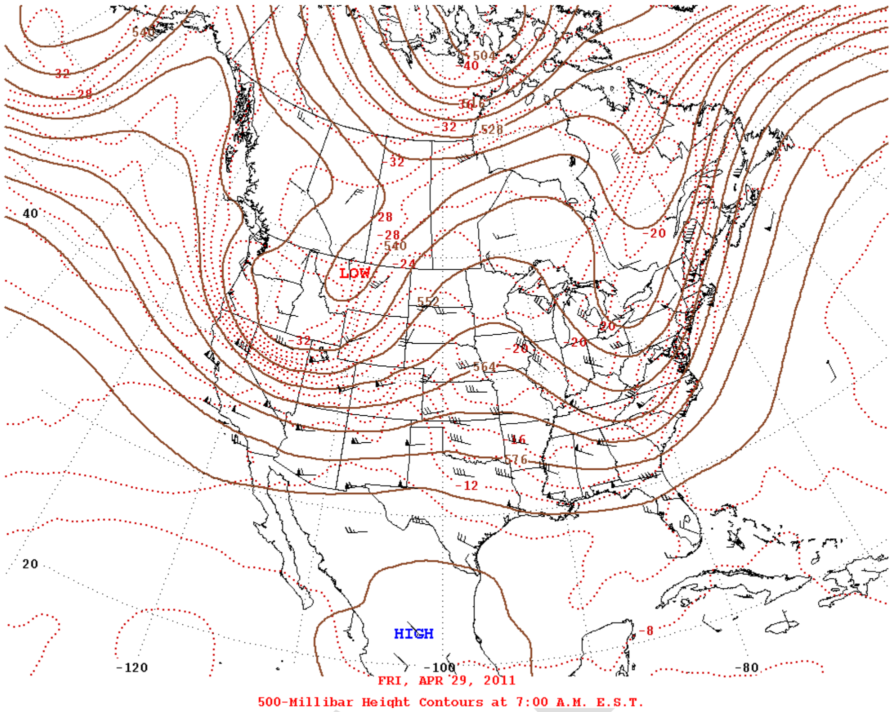


Figure 6-15. 500 mb heights for 06:00 on April 29, 2011 (Smoke-Event Day), showing a ridge of high pressure over Kansas. Source: NWS.

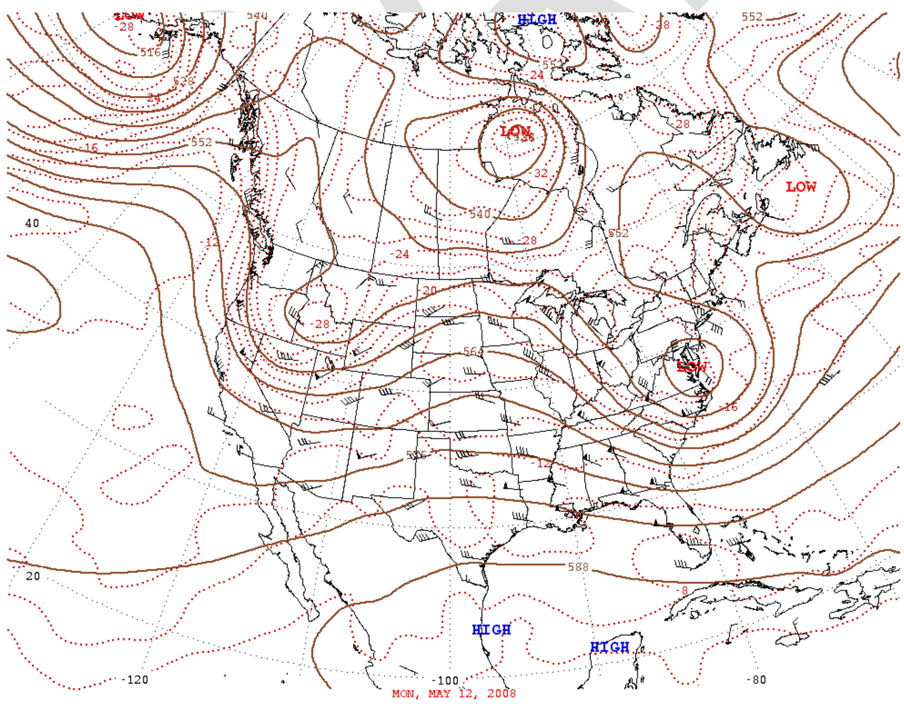


Figure 6-16. 500 mb heights for 06:00 on May 12, 2008 (Matching Day 1), showing a ridge of high pressure over Kansas. Source: NWS.

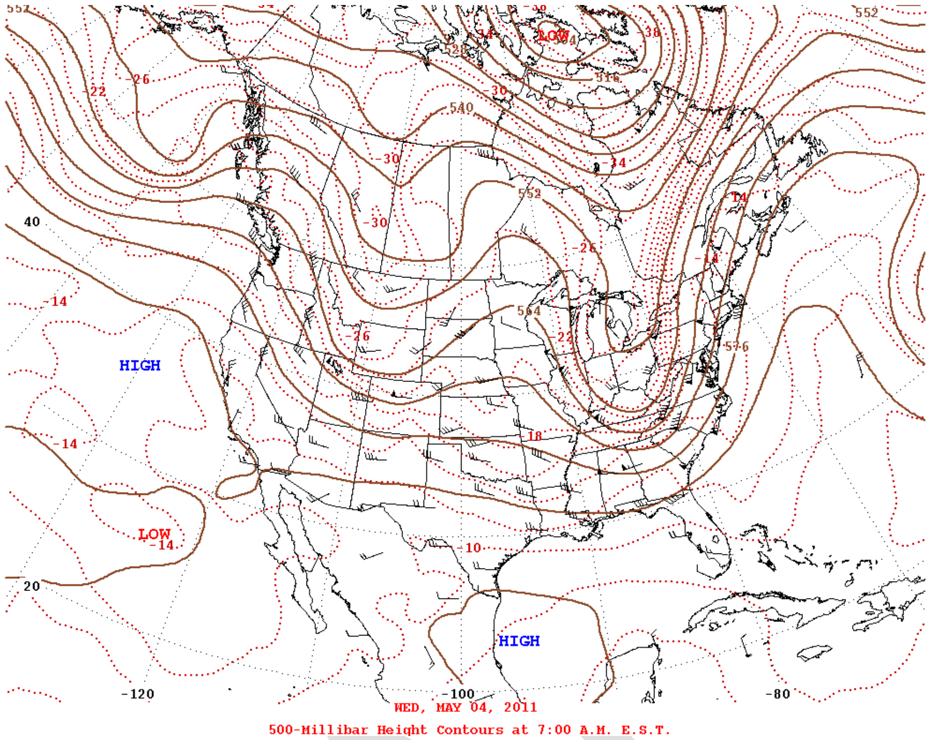


Figure 6-17. 500 mb heights for 06:00 on May 4, 2011 (Matching Day 2), showing a ridge of high pressure over Kansas. Source: NWS.

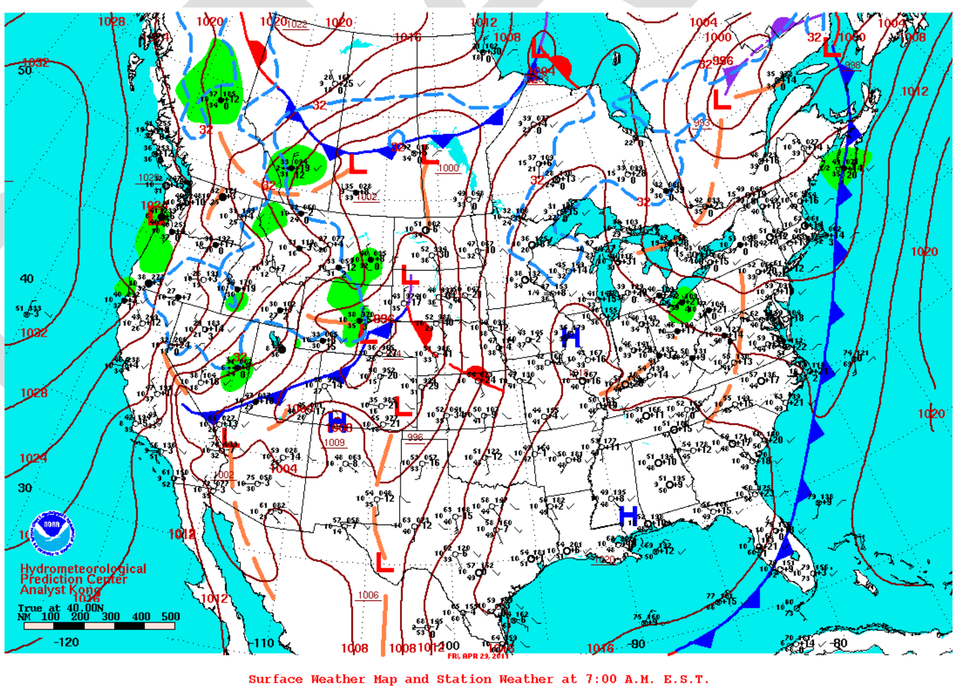


Figure 6-18. Surface map for 06:00 on April 29, 2011 (Smoke-Event Day, showing high pressure over the Mississippi Valley with moderate southerly flow over Kansas. Source: NWS.

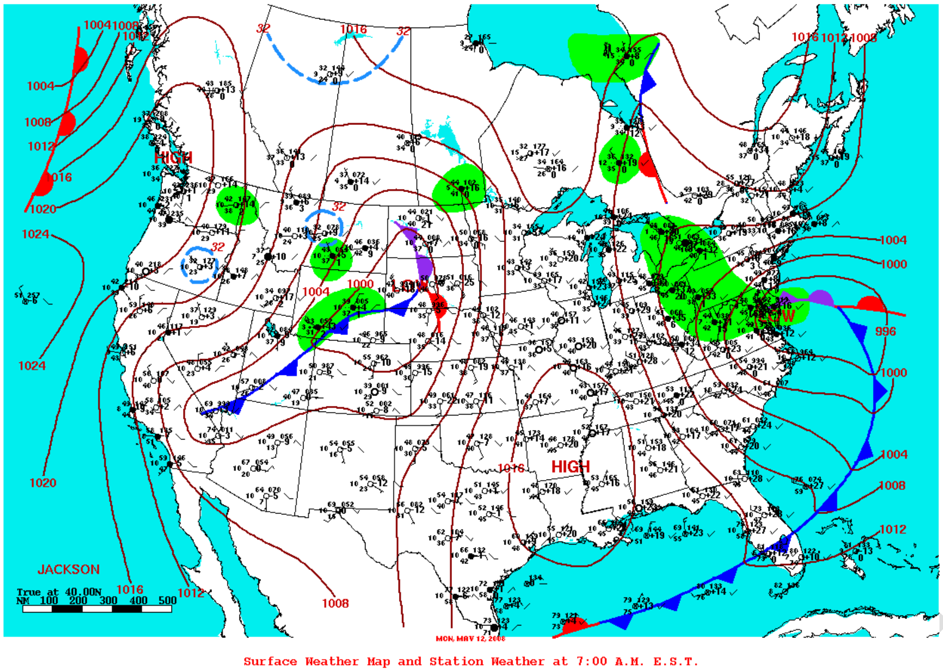


Figure 6-19. Surface map for 06:00 on May 12, 2008 (Matching Day 1), showing high pressure over the Mississippi Valley with moderate southerly flow over Kansas. Source: NWS.

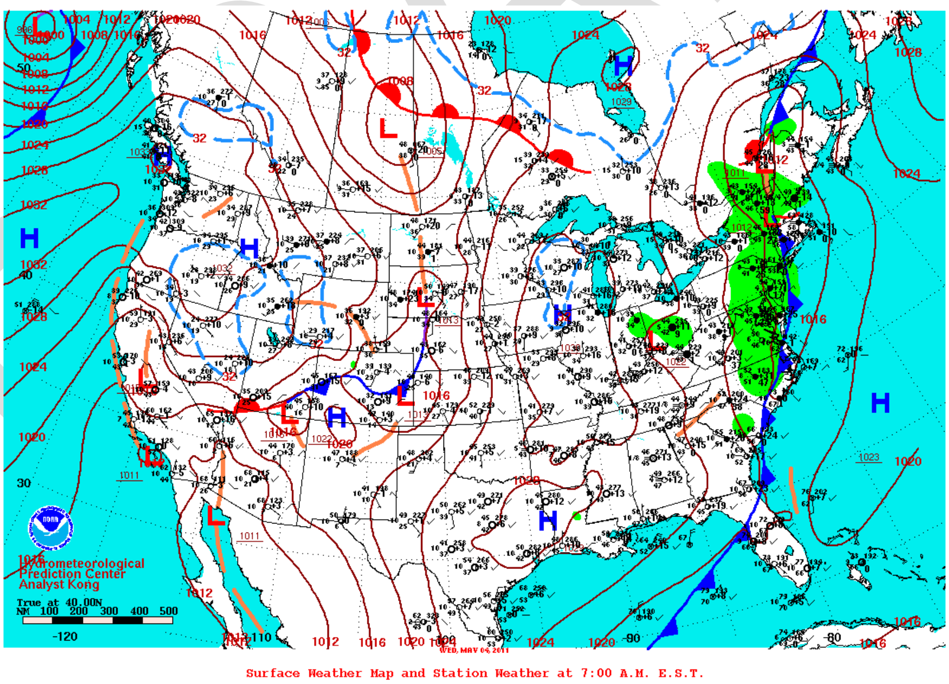


Figure 6-20. Surface map for 06:00 on May 4, 2011 (Matching Day 2), showing high pressure over the Mississippi Valley with moderate southerly flow over Kansas. Source: NWS.

Table 6-5. Meteorological conditions and 8-hour ozone concentrations on April 29, 2011, and associated matching days. Meteorological conditions were similar on all days, but ozone concentrations on the matching days were lower and were below the NAAQS.

Parameter	April 29, 2011 (Event Day)	May 12, 2008 (Matching Day 1)	May 4, 2011 (Matching Day 2)
Wichita High Temp (°F)	81	75	79
Wichita Low Temp (°F)	46	45	50
Wichita 6 a.m. to 12 p.m. Wind Speed (kts)	15.9	14.3	15.7
Wichita 6 a.m. to 12 p.m. Wind Direction (°)	177	168	187
Wichita 12 to 6 p.m. Wind Speed (kts)	31.4	22.8	23.5
Wichita 12 to 6 p.m. Wind Direction (°)	180	171	193
Topeka 12Z 850 Temp (°C)	11.6	11.6	7.6
Topeka 12Z 500 mb Height (m)	5670	5710	5720
Solar Radiation	NA	NA	NA
Cloud Cover	Sunny	Sunny	Sunny
Surface Pattern	Gulf Coast high	Gulf Coast high	Gulf Coast high
500 mb Pattern	Ridge over Kansas	Ridge over Kansas	Ridge over Kansas
Peck Ozone (ppm)	0.077	0.057	0.062
Sedgwick Ozone (ppm)	0.082	0.055[a]	0.056

[a] The Sedgwick monitor was not in service until 2009. Data from W. Park City, the ozone monitor nearest to Sedgwick, were used as a surrogate for May 12, 2008.

6.4 Modeling

6.4.1 Methods

A retrospective modeling analysis was performed to quantify the impacts of emissions from prescribed fires in the Flint Hills region on air quality at the Kansas monitoring sites during April 2011, and to assess whether the 8-hour ozone concentrations above 0.075 ppm in April 2011 would have occurred without the influence of emissions from these fires. To assess the impact of smoke on ozone levels, model simulations were performed with and without estimated smoke emissions from the fires. The difference in ozone concentrations between these two simulations provides a quantitative estimate of the impact of Flint Hills fires on ozone concentrations at the monitoring sites. This section summarizes the methods and modeling approach used in this analysis.

Modeling System

The modeling analysis was performed using the BlueSky Gateway air quality modeling system. BlueSky Gateway is an operational air quality forecasting system developed by the USDA Forest Service to predict nationwide air quality impacts due to wildfires and other emission sources at 36-km resolution. BlueSky Gateway components include the BlueSky Framework for estimating fire emissions, the Pennsylvania State University/National Center for

Atmospheric Research Mesoscale Model (MM5) for predicting meteorological conditions, the Community Multiscale Air Quality (CMAQ) model for predicting gaseous and particulate pollutant concentrations, and the Sparse Matrix Operator Kernel Emissions (SMOKE) processing system for incorporating anthropogenic emissions. BlueSky Gateway has produced twice daily ozone and $PM_{2.5}$ forecasts for the contiguous United States since summer 2007 (Craig et al., 2007).

Emissions Inventory

For fires outside the Flint Hills region, daily fire locations and sizes were provided by the Satellite Mapping Automatic Reanalysis Tool for Fire Incident Reconciliation (SmartFire) version 1 (Raffuse et al., 2006), which integrates and reconciles human-recorded wildfire incident data with satellite-detected fire data and NOAA HMS smoke plume analyses. The BlueSky Framework was used to develop emissions estimates from the SmartFire burn area predictions. This methodology is similar to that currently used by USEPA for developing national fire emission inventories (Sullivan et al., 2009).

For fires within the Flint Hills region, independent county-level burn acreage data were developed by KDHE and Kansas State University using satellite fire detects and local burn scar information. KDHE also provided fuel loading data, typical burn size distributions, and sub-county spatial burn distributions based on local knowledge of the vegetation present during April 2011 and typical burning practices in the Flint Hills. A refined spatial allocation approach was used to provide appropriate inputs to the BlueSky Framework and develop gridded hourly Flint Hills fire emissions data. The default fuel loading maps in the BlueSky Framework were bypassed in favor of local fuel loading data from KDHE. A consumption efficiency of 100% was assumed because prescribed burns in the Flint Hills consume most available grassland fuel. Although most of the fuel in these types of burns is consumed by the flaming phase of the fire, some smoldering does occur after the flame front passes, and thus a smoldering fraction of 10% was applied. A diurnal time profile was applied to all Flint Hills fire emissions to simulate a typical Flint Hills prescribed burn that starts at 10:00 CDT and burns evenly across the landscape for 8 consecutive hours.

For several days in April 2011, KDHE fire information was unavailable, and SMARTFIRE data were used instead. This substitution did not occur on the most active burn days in the Flint Hills, and the ozone NAAQS were not exceeded on any date when SMARTFIRE data were used. **Table 6-6** summarizes the daily burn acreage estimates for the Flint Hills region during April 2011.

Non-fire anthropogenic emissions from the 2008 National Emission Inventory Version 1.5 were processed through SMOKE. These emissions were not increased for 2011 because economic recession limited growth in vehicle miles traveled and mobile source emissions between 2008 and 2011. Average meteorological conditions for April 2011 were used to prepare temperature-dependent emissions, such as mobile and biogenic sources.

Table 6-6. Daily Flint Hills burn acreage estimates and data sources for April 2011. Bold entries indicate dates on which 8-hour ozone concentrations were above 0.075 ppm in Kansas. The KDHE method for burn acreage estimates is described in section 4.3.1.

Date	Acres Burned	Source
4/1/2011	43,997	SmartFire
4/2/2011	83,271	SmartFire
4/3/2011	21,656	SmartFire
4/4/2011	1,829	KDHE method
4/5/2011	142,982	KDHE method
4/6/2011	**248,358**	**KDHE method**
4/7/2011	34,469	KDHE method
4/8/2011	178,071	KDHE method
4/9/2011	84,244	KDHE method
4/10/2011	7,133	KDHE method
4/11/2011	136,975	KDHE method
4/12/2011	**298,243**	**KDHE method**
4/13/2011	**291,296**	**KDHE method**
4/14/2011	58,259	KDHE method
4/15/2011	185	KDHE method
4/16/2011	233,036	KDHE method
4/17/2011	27,373	SmartFire
4/18/2011	23,284	SmartFire
4/19/2011	2,134	SmartFire
4/20/2011	17,094	SmartFire
4/21/2011	613	SmartFire
4/22/2011	5,624	SmartFire
4/23/2011	1,500	SmartFire
4/24/2011	944	SmartFire
4/25/2011	110	KDHE method
4/26/2011	3,207	KDHE method
4/27/2011	880	KDHE method
4/28/2011	139,697	KDHE method
4/29/2011	**19,134**	**KDHE method**
4/30/2011	13,104	KDHE method

Modeling Analysis Method

BlueSky Gateway was used to model ozone concentrations in Kansas during April 2011. The simulations were carried out as a series of overlapping two-day runs initialized each day at 00 UTC. Each daily simulation was initialized from previous days' modeled concentrations to account for the carryover of primary and secondary pollutants produced from prior days' emissions. Simulations were started on March 25, 2011, to provide an adequate spin-up period, but only results from April are used in the analysis. Although the analysis focuses on the four ozone exceedance dates, BlueSky Gateway was executed each day of the month to preserve pollutant carryover effects, provide day-to-day continuity to the concentration fields, and provide additional context for assessing model performance. Peak 8-hour average ozone concentrations were calculated from the hourly model predictions from 00:00 to 23:00 CDT on the first day of each daily model run (i.e., the same-day forecast).

To isolate the impacts of Flint Hills fire emissions on ozone concentrations in Kansas, and to assess whether exceedances of the 8-hour ozone standard would not have occurred but for the smoke impacts from Flint Hills fires, two simulations were performed.

1. A base case simulation to model ozone concentrations due to all anthropogenic, biogenic, and fire emissions sources, including emissions from Flint Hills fires.
2. A sensitivity simulation with Flint Hills fire emissions removed from the emission inventory.

The difference in ozone concentrations between these two simulations provides a quantitative estimate of the impact of Flint Hills fires on ozone concentrations. Note that although BlueSky Gateway incorporates the effects of fire emissions from fires outside the Flint Hills on ozone production, only the ozone increment resulting from Flint Hills fires is analyzed here, because both simulations include ozone contributions due to fires outside the Flint Hills. It is important to note that the April 29, 2011, event was likely the result of fires in Texas and northern Mexico. Thus, because BlueSky does not currently account for fires outside the United States (e.g., Mexico), the model simulations were not accurate for April 29 and the model results were not used in the But For demonstration for this date.

6.4.2 Model Performance

To assess ozone model performance in Kansas during April 2011, near-surface peak 8-hour average ozone concentrations were extracted from the model output at the six Kansas ozone monitors and compared against the monitored data. Time series comparisons are shown in **Figure 6-21**. BlueSky Gateway adequately captured most of the important ozone trends observed during April 2011, including variations driven by emissions from Flint Hills fires. A summary of model performance metrics are presented in **Table 6-7**.

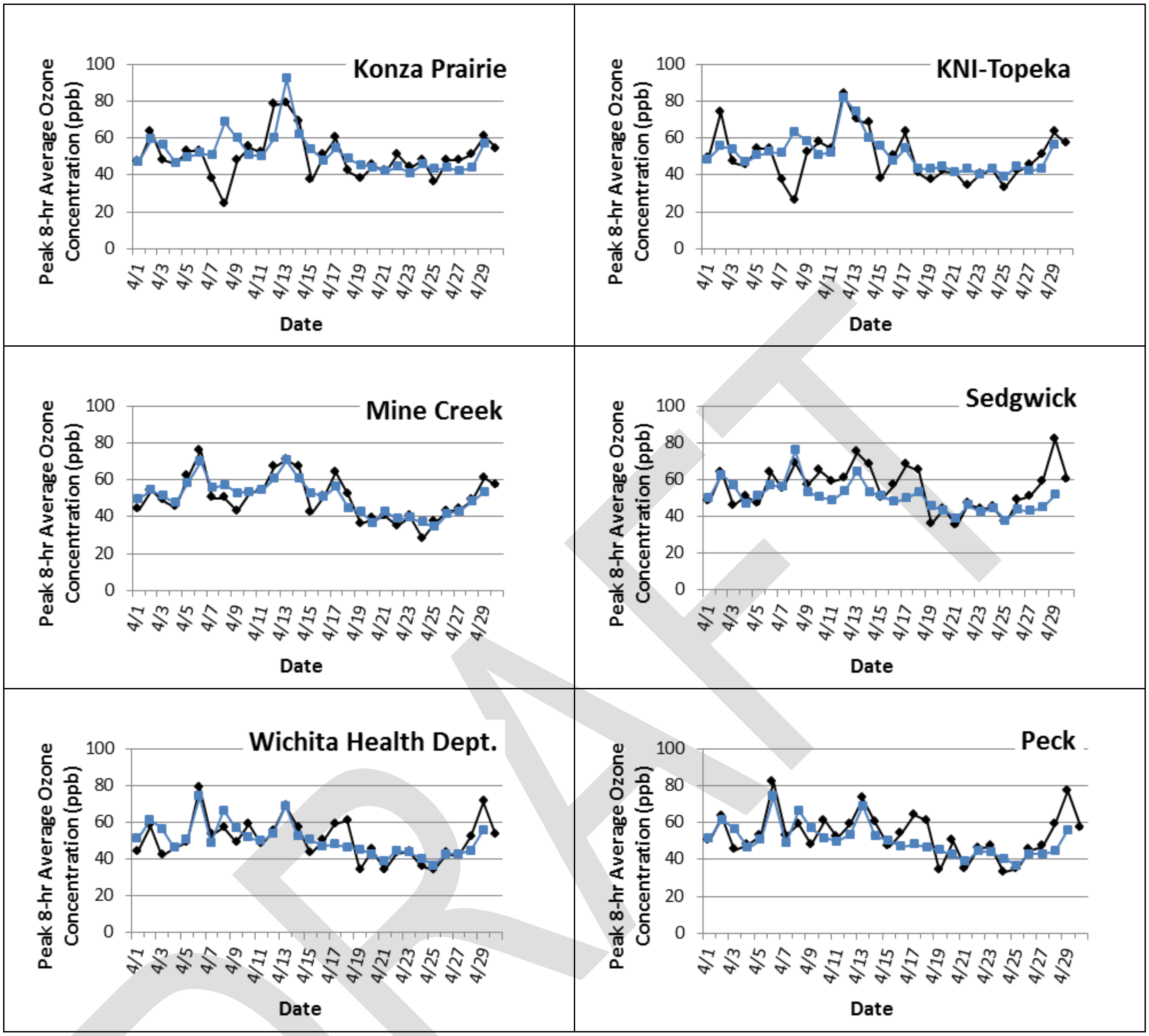


Figure 6-21. Time series of observed (black) and predicted (blue) peak 8-hour average ozone concentrations at the Kansas monitoring sites during April 2011.

Table 6-7. Summary of model verification metrics by monitor.

Monitor	Mean Bias (ppb)	Mean Absolute Error
Konza Prairie	1.7	18%
KNI-Topeka	1.8	16%
Mine Creek	0.5	9%
Sedgwick	-4.5	12%
Wichita Health Dept.	0.2	11%
Peck	-2.7	12%

The model performance was good on most April days, including April 6, 12, and 13. Therefore, we determined that the model can be used as evidence in the But For demonstration. On April 7 and 8, the modeling system failed to capture low ozone levels observed at the Konza Prairie and Topeka monitors because the MM5 failed to capture low-level cloud cover and cool temperatures in northern Kansas; these conditions limited ozone formation. On April 29, the modeling system failed to capture the elevated ozone levels at monitors regionwide because smoke contributions from fires in Mexico and Central America were not considered; those fires likely contributed to ozone formation in the Wichita area on April 29. Other observations on model performance include

- The modeling system captured the timing and magnitude for many of the observed elevated ozone events during April 2011.
- Ozone concentrations were higher (50 to 70 ppb) during the first half of April when Flint Hills burning was active, and lower (40 to 50 ppb) during the second half of April when Flint Hills burning was less active and weather conditions were generally cool and cloudy. The modeling system captured this regional trend.
- The mean absolute error in predicted peak 8-hour ozone concentrations ranges from 9% to 18% across the Kansas monitors, which is considered to be acceptable model performance[6].

6.4.3 Results

This section summarizes the results of the modeling analysis for each day in April 2011 when 8-hour ozone concentrations were above 0.075 ppm. Brief synopses of the important meteorological and air quality conditions are presented here; more detailed analyses can be found in the Causal Relationship section of this report. To provide context for the modeling analysis, plots of the NOAA HMS smoke plumes, fire locations, winds at 16:00 CST, and HYSPLIT trajectories from AIRNow-Tech are also presented.

Each daily analysis also includes a plot of the difference in modeled peak 8-hour average ozone concentrations between the base case (with Flint Hills fires) and sensitivity (no Flint Hills fires) simulations; the differences represent the modeled impact of Flint Hills fire emissions on ozone concentrations. The plots indicate the areas where additional NO_x and VOC emissions from Flint Hills fires were sufficient to impact ozone production, and therefore represent the spatial extent of the modeled smoke plume that resulted from Flint Hills fires. Plots showing the differences in VOC and NO_x emissions between the base case and sensitivity simulations by hour on April 6, 12, and 13, 2011 are shown in **Appendix D**. The base case and sensitivity simulations showed no differences in VOC and NO_x emissions for April 29, 2011; this is because the fires on that day occurred mostly in Texas and northern Mexico and not in the Flint Hills region.

[6] U.S. Environmental Protection Agency (1991) Guideline for regulatory application of the Urban Airshed Model (UAM). Report prepared by U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC, EPA-450/4-91-013.

Smoke Event Day: April 6, 2011
Impacted Monitors: Mine Creek, Wichita Health Department, Peck

A cold front was passing through Kansas on April 6, with southerly winds ahead of the front and northerly winds behind the front. After the front passed through Wichita around midday, northerly winds transported smoke from the Flint Hills fires to the Wichita and Peck monitors. As the cold front approached the Mine Creek monitor, southwesterly winds transported smoke from the Flint Hills fires to the Mine Creek monitor. Northerly winds behind the front transported smoke away from monitors in northeastern Kansas. A large smoke plume was present over southern and eastern Kansas (**Figure 6-22**).

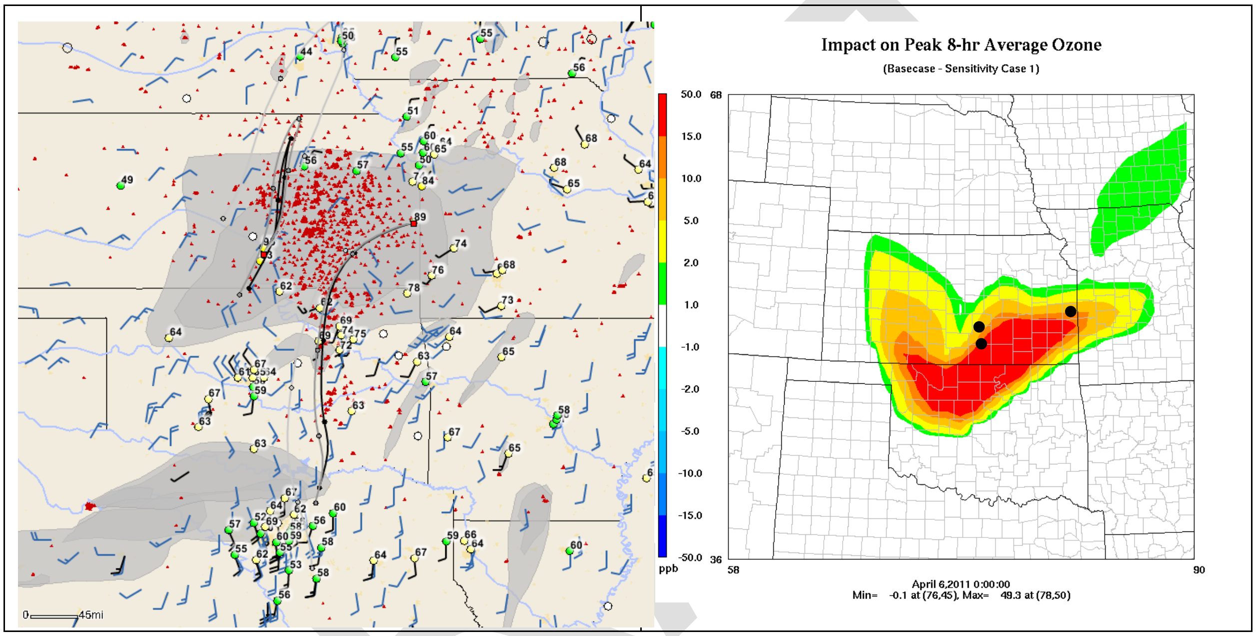


Figure 6-22. Left: Surface winds, smoke coverage, and fire locations at 16:00 on April 6, 2011. Red dots and gray shading show fire and smoke locations, respectively. Lines indicate 24-hour back trajectories ending at the impacted monitors. Plot created in AIRNow-Tech. Right: Ozone difference plot representing modeled ozone concentrations directly caused by fires in the Flint Hills region. Black dots represent approximate locations of the impacted monitors.

The modeled fires on April 6 produced a smoke plume over southern and eastern Kansas. The modeled plume looked similar to the observed plume and affected all three monitors that recorded 8-hour ozone concentrations above 0.075 ppm. The additional NO_x and VOC emissions from the fires led to an enhancement of ozone concentrations over these areas.

When compared with the predicted concentrations at monitors unaffected by the smoke plume, the base case simulation captures a significant ozone enhancement at all three impacted monitors (**Table 6-8**). The base case simulation also captures a less significant ozone enhancement at the Sedgwick monitor, although ozone concentrations there remained below the federal 8-hour ozone standard. The KNI-Topeka and Konza Prairie monitors were largely unaffected by the smoke plume, and the model accurately predicted regional background ozone levels (around 0.053 ppm) at those monitors. Modeled ozone concentrations were 0.005 to 0.008 ppm higher than the observations at the impacted monitors.

The predicted difference between the base case simulation (with Flint Hills fires) and the sensitivity simulation (without Flint Hills fires) suggests that the ozone enhancement at the impacted monitors was caused by emissions from fires in the Flint Hills region. The modeled impact of Flint Hills fires was 0.020 ppm at the Wichita and Peck monitors and 0.010 ppm at the Mine Creek monitor. The modeled ozone concentrations for the sensitivity simulation were well below the federal 8-hour ozone standard, demonstrating that the observed 8-hour ozone concentrations above 0.075 ppm would not have occurred but for the smoke.

Table 6-8. Modeled impact of Flint Hills fires on 8-hour average ozone concentrations at the Kansas air monitors on April 6, 2011. Bold values indicate data at the impacted monitors.

Monitor	Peak 8-hr Average Ozone Concentration (ppm)			
	Observed	Base Case (All Fires)	Without Flint Hills Fires	Impact of Flint Hills Fires
Mine Creek	**0.076**	**0.070**	**0.060**	**0.010**
Wichita Health Department	**0.079**	**0.074**	**0.054**	**0.020**
Sedgwick	0.064	0.057	0.052	0.005
KNI-Topeka	0.054	0.053	0.052	0.000
Peck	**0.082**	**0.074**	**0.054**	**0.020**
Konza Prairie	0.053	0.052	0.051	0.001

Smoke Event Day: April 12, 2011
Impacted Monitors: KNI-Topeka, Konza Prairie

Light to moderate southerly winds in eastern Kansas on April 12 transported smoke from fires in the Flint Hills region to the KNI-Topeka and Konza Prairie monitors. This wind pattern transported smoke away from the Wichita-area monitors in southern Kansas and the Mine Creek monitor in eastern Kansas. A large smoke plume was present over eastern Kansas, primarily over the Flint Hills region with some northward extension in to northern Kansas. (**Figure 6-23**).

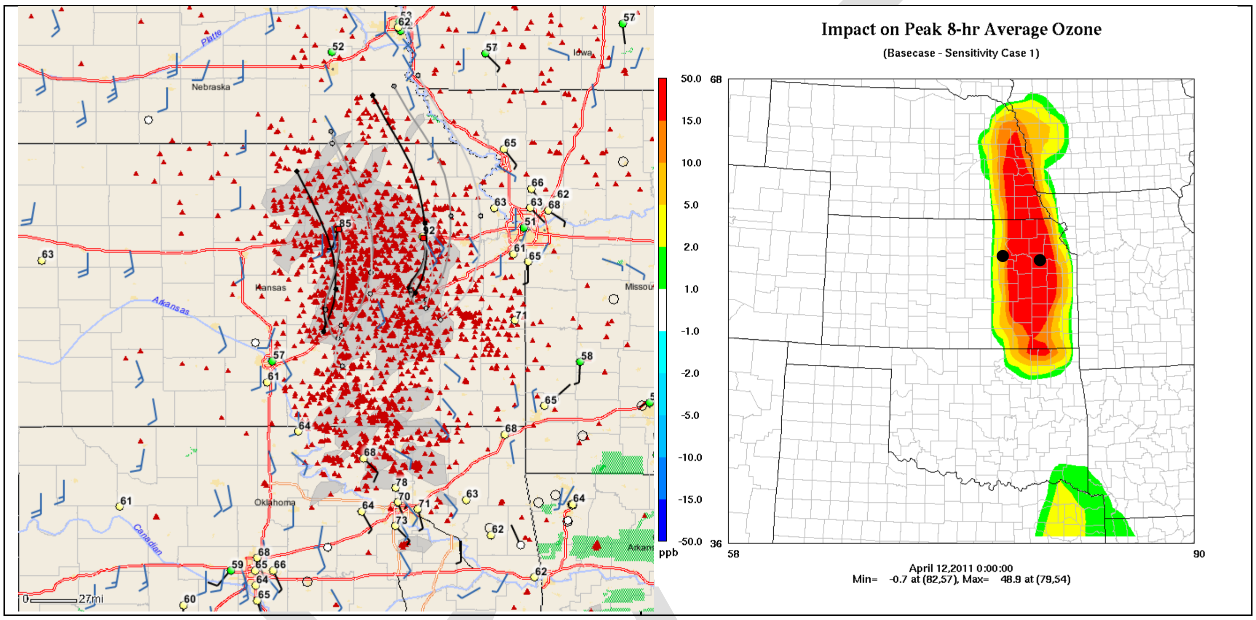


Figure 6-23. Left: Surface winds, smoke coverage, and fire locations at 16:00 on April 12, 2011. Red dots and gray shading show fire and smoke locations, respectively. Black lines indicate 24-hour backward trajectories ending at the impacted monitors. Plot created in AIRNow-Tech. Right: Ozone difference plot representing modeled ozone enhancement due to emissions from fires in the Flint Hills region. Black dots represent approximate locations of the impacted monitors.

The modeled fires and wind patterns on April 12 produced an elongated smoke plume over the Flint Hills region. The modeled plume looks similar to the observed plume, but the modeled plume is narrower and longer. The modeled plume impacted both the KNI-Topeka and Konza Prairie monitors. The additional NO_x and VOC emissions from the fires led to an enhancement of ozone concentrations over these same areas.

Because the modeled smoke plume is directly over the KNI-Topeka monitor, the base case simulation captures a significant ozone enhancement at KNI-Topeka compared with ozone concentrations at monitors unaffected by the smoke plume (e.g., Wichita and Peck). The base case simulation accurately depicted the peak 8-hour ozone concentration at KNI-Topeka. The base case simulation also captured some ozone enhancement at the Konza Prairie monitor, but the modeled smoke plume was so narrow that most of it missed Konza Prairie; the model therefore did not capture the full ozone enhancement there. Although the NOAA-HMS data did not depict a smoke plume over the Mine Creek monitor, some fires were burning in that region, and the observed 8-hour ozone concentration of 0.067 ppm suggests some ozone enhancement which was not captured in the model. The Wichita Health Dept. and Peck monitors were unaffected by the smoke plume, and the model correctly predicted background ozone concentrations below 0.060 ppm at those monitors.

The predicted difference between the base case simulation (with Flint Hills fires) and the sensitivity simulation (without Flint Hills fires) at the KNI-Topeka monitor suggests that the ozone enhancement was caused by emissions from fires in the Flint Hills region (**Table 6-9**). The modeled 8-hour ozone concentration at KNI-Topeka without the fires was 0.054 ppm, which is well below the federal 8-hour ozone standard, and demonstrates that the observed 8-hour ozone concentration of 0.084 ppm at KNI-Topeka would not have occurred but for the fires. A definitive conclusion at Konza Prairie was not possible, as the modeling system did not adequately capture the ozone enhancement at that monitor. However, subtracting the estimated 0.007 ppm contribution due to smoke from the observed 8-hour concentration of 0.078 ppm would result in an 8-hour ozone concentration below the federal ozone standard, suggesting that the observed 8-hour concentration of 0.078 ppm at Konza Prairie would not have occurred but for the smoke impact.

Table 6-9. Modeled impact of Flint Hills fires on 8-hour average ozone concentrations at the Kansas air monitors on April 12, 2011. Bold values indicate data at the impacted monitors.

Monitor	Peak 8-hr Average Ozone Concentration (ppm)			
	Observed	Base Case (All Fires)	Without Flint Hills Fires	Impact of Flint Hills Fires
Mine Creek	0.067	0.060	0.060	0.000
Wichita Health Department	0.055	0.054	0.053	0.001
Sedgwick	0.061	0.054	0.054	0.000
KNI-Topeka	**0.084**	**0.082**	**0.054**	**0.028**
Peck	0.059	0.054	0.053	0.001
Konza Prairie	**0.078**	**0.060**	**0.053**	**0.007**

Smoke Event Day: April 13, 2011
Impacted Monitor: Konza Prairie

Light to moderate southeasterly surface winds in eastern Kansas on April 13 transported smoke from fires in the Flint Hills region toward the Konza Prairie monitor. Unlike the previous day, when smoke was confined to the Flint Hills region, smoke on April 13 was observed over most of Kansas and portions of neighboring states (**Figure 6-24**). Some of this smoke was likely the result of fires on the previous day.

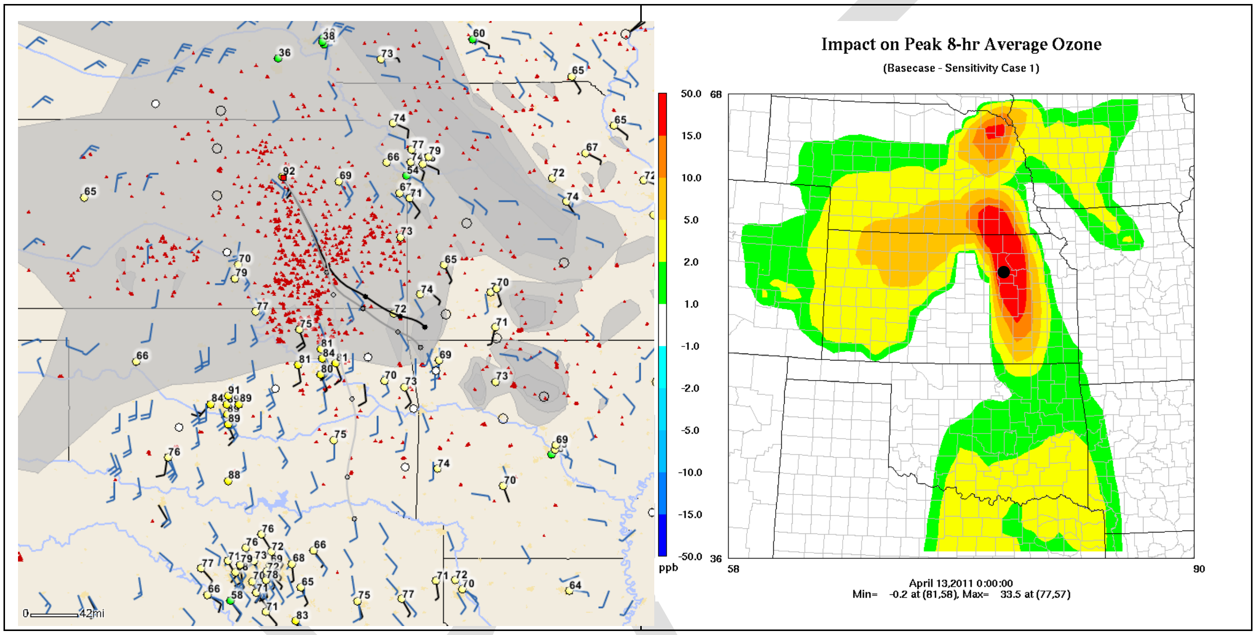


Figure 6-24. Left: Surface winds, smoke coverage, and fire locations at 16:00 on April 13, 2011. Red dots and gray shading show fire and smoke locations, respectively. Plot created in AIRNow-Tech. Black lines indicate 24-hour backward trajectories ending at the impacted monitor. Right: Ozone difference plot representing modeled ozone enhancement due to emissions from fires in the Flint Hills region. Black dots represent approximate locations of the impacted monitors.

The combination of modeled fires and wind patterns on both April 12 and 13 produced a significant region of smoke over much of the central United States. The modeled smoke impacts were most concentrated over the Flint Hills region, and the additional NO_x and VOC emissions from the Flint Hills fires led to a large ozone enhancement in this region, which includes the Konza Prairie monitor. Modeled ozone impacts outside the Flint Hills were the result of smoke that was generated on the previous day and transported away from the Flint Hills region.

With the exception of KNI-Topeka, both observed and modeled ozone concentrations at all monitors increased on April 13 from the previous day (**Table 6-10**). At the monitors other than Konza Prairie, however, the modeled ozone impacts due to Flint Hills fires were no more than 0.002 ppm. The regional ozone enhancement on this day was likely due to a combination of ozone and precursor emissions from fires that burned the previous day, and photochemical production that would have occurred even without Flint Hills fire emissions.

The model predicted an ozone enhancement of 0.030 ppm at the Konza Prairie monitor due to the Flint Hills fires. Because the base case simulation overpredicted the 8-hour ozone concentration at Konza Prairie by 0.013 ppm, the modeled ozone impact from the Flint Hills fires was likely overestimated as well. However, the 8-hour ozone concentration at the Konza Prairie monitor exceeded the federal 8-hour ozone standard by only 0.004 ppm, indicating that even a small ozone enhancement from smoke would have been sufficient to cause an 8-hour ozone concentration over 0.075 ppm. The predicted difference between the base case simulation (with Flint Hills fires) and the sensitivity simulation (without Flint Hills fires) at the Konza Prairie monitor suggests that the observed 8-hour ozone concentration of 0.079 ppm would likely not have occurred but for the smoke.

Table 6-10. Modeled impact of Flint Hills fires on 8-hour average ozone concentrations at the Kansas air monitors on April 13, 2011. Bold values indicate data at impacted monitors.

Site	Peak 8-hr Average Ozone Concentration (ppm)			
	Observed	Base Case (all fires)	Without Flint Hills Fires	Impact of Flint Hills Fires
Mine Creek	0.071	0.070	0.070	0.000
Wichita Health Department	0.069	0.069	0.068	0.001
Sedgwick	0.075	0.065	0.064	0.001
KNI-Topeka	0.070	0.075	0.073	0.002
Peck	0.073	0.069	0.068	0.001
Konza Prairie	**0.079**	**0.092**	**0.062**	**0.030**

Smoke-Event Day: April 29, 2011
Impacted Monitors: Sedgwick, Peck

Numerous large fire complexes in Texas and northern Mexico, some burning since April 25, produced widespread smoke across the southern Plains on April 29 (**Figure 6-25**). Strong southerly surface winds in excess of 30 knots transported this smoke into Kansas. The Wichita area monitors were closer to the smoke sources than the other Kansas monitors and were therefore impacted for a longer period of time.

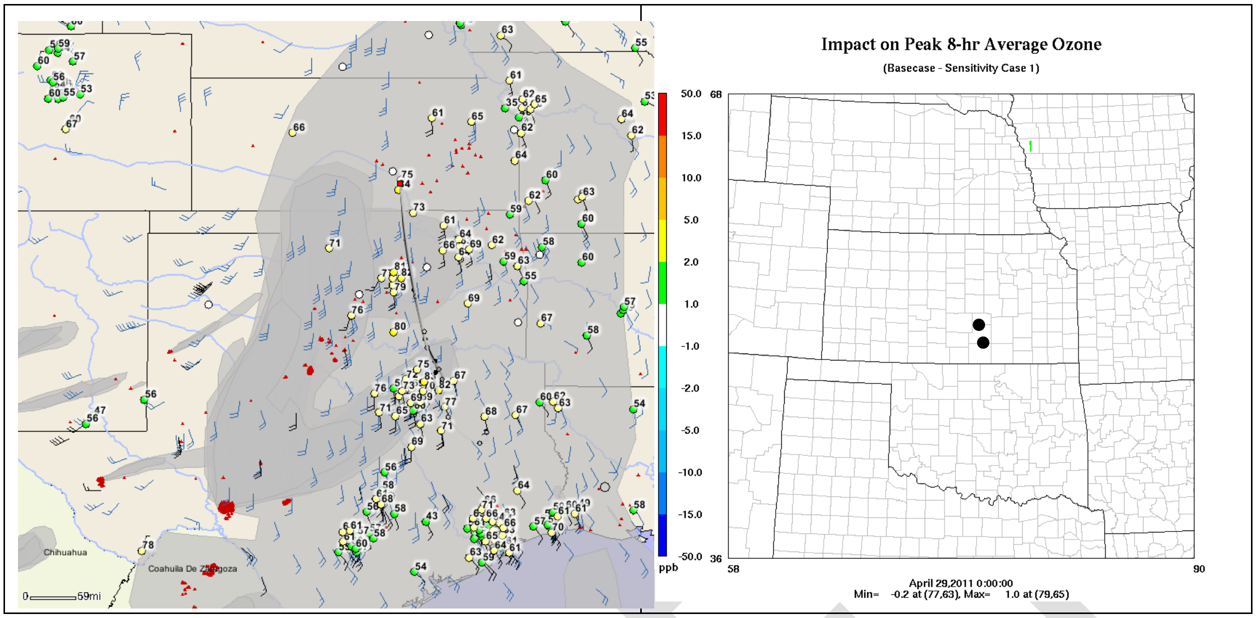


Figure 6-25. Left: Surface winds, smoke coverage, and fire locations on April 29, 2011. Red dots and gray shading show fire and smoke locations, respectively. Smoke coverage is derived from an integrated smoke plume analysis from NOAA-HMS. Right: Ozone difference plot representing modeled ozone enhancement due to fires in the Flint Hills region. Black dots represent approximate locations of the impacted monitors.

The modeling analysis showed no ozone impacts at the Kansas monitors due to Flint Hills fires. Very few fires were burning in the Flint Hills region on April 29, and therefore the 8-hour ozone concentrations over 0.075 ppm cannot be explained by local Flint Hills burning.

As was described in the Methods section, BlueSky Gateway cannot be used to fully assess the impacts of non-local burning on ozone concentrations at the Kansas monitors on April 29, as the model did not accurately predict the observed ozone concentrations at Kansas monitors. BlueSky Gateway predicted ozone concentrations of 0.052 to 0.057 ppm at all Kansas monitors, whereas observed 8-hour ozone concentrations were over 0.075 ppm at the Sedgwick and Peck monitors. The large fires in Texas were captured by the modeling system, but the modeled smoke from those fires was insufficient to impact regional ozone levels in Kansas. However, smoke from the fires in northern Mexico was transported northward and likely impacted air quality in the Wichita area. Thus, because BlueSky does not currently account for fires outside the United States, the model simulations were not accurate for April 29. The model results were not used in the But For demonstration for this date.

7. Conclusions

In April 2011, air quality in Kansas was affected by smoke from widespread fires in the Flint Hills region and across the southern Plains. Peak daily 8-hour ozone concentrations were above the federal 8-hour standard of 0.075 ppm at one or more Kansas monitors on four days in April 2011. This report assesses whether the 8-hour ozone concentrations above 0.075 ppm were Exceptional Events. The analyses in this report demonstrate that the 8-hour ozone concentrations above 0.075 ppm meet the criteria for designation as Exceptional Events. Specifically, we found that the 8-hour ozone concentrations above 0.075 ppm

1. Were not reasonably preventable (Section 3);
2. Were caused by smoke from fires (Section 4);
3. Were unusual compared to historical norms (Section 5); and
4. Would not have occurred but for the smoke (Section 6).

8. Public Comments

Reserved for public comments

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